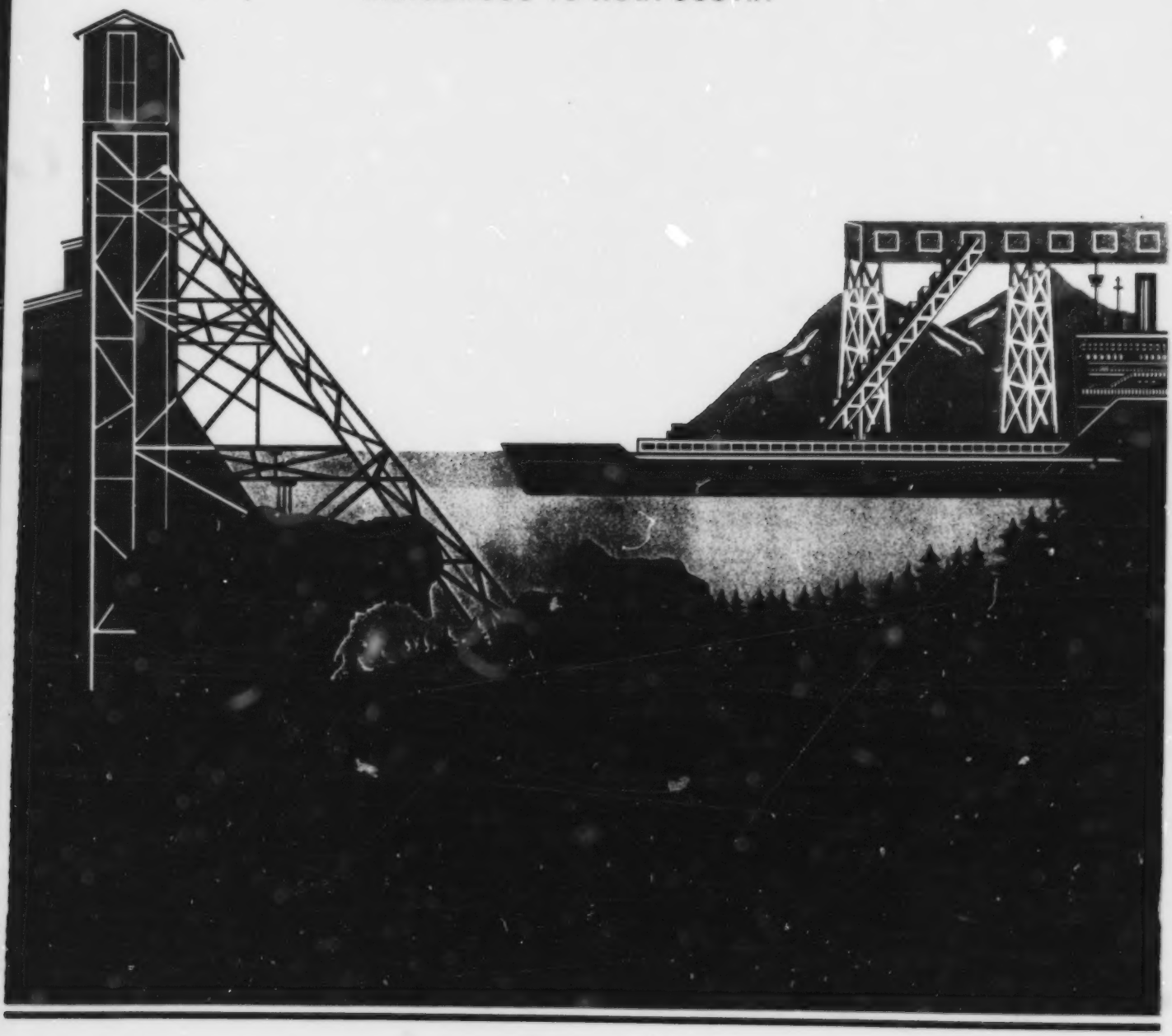
Canada - Nova Scotia
Mineral Development Agreement

INVESTIGATIONS TO DETERMINE POTENTIAL APPLICATIONS FOR ANHYDRITE RESOURCES INDIGENOUS TO NOVA SCOTIA



Canada

Nova Scotia

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TECHNICAL UNIVERSITY OF NOVA SCOTIA

INVESTIGATIONS TO DETERMINE POTENTIAL APPLICATIONS FOR ANHYDRITE RESOURCES INDIGENOUS TO NOVA SCOTIA

A Report prepared under
DSS Contract 23440-7-9035/01-ST
and administered by CANMET

153 pp

MICROMEDIA

Funding for this project was provided under the
Canada - Nova Scotia Minerals Development Agreement
September, 1989

EXECUTIVE SUMMARY

Minor quantities of anhydrite ($CaSO_4$) are produced annually in Nova Scotia from high quality (+95% $CaSO_4$) anhydrite deposits that are estimated to contain billions of tonnes of this resource. Some anhydrites when crushed and combined with water and the necessary chemical accelerators will develope into a cementitious material that has industrial applications. Potential uses of anhydrite were identified as a 'pack' construction material in underground coal mines (this practice is currently used in Europe) and in the production of anhydrite based plasters for application in wallboard manufacturing (replacing calcined gypsum or "hemihydrate") and floor screed preparations.

Section I: Anhydrite samples were collected from four Nova Scotia gypsum producers. Laboratory tests were performed using a range of product sizes of crushed anhydrite, water/solids ratios and a variety of chemical accelerators to identify the mechanical properties of the 'cured' anhydrite. This testing identified that the anhydrite from Georgia Pacific Corporation did not possess adequate cementing characteristics to be of further interest in this investigation. The anhydrite from Fundy Gypsum Co. Ltd. and National Gypsum (Canada) Ltd. demonstrated marginally acceptable properties while the Little Narrows Co. Ltd. anhydrite showed excellent potential to be used as a mine

'pack' construction material in coal mines. Macroscopic and microscopic analysis of the anhydrite materials were performed and crystal differences that could explain the variation in performance of these anhydrite materials is discussed. Extended mechanical testing of the Little Narrows Co. Ltd. anhydrite was done to determine the optimum mix of anhydrite, accelerator and water for the mine 'pack ' application. The beneficial affects of adding Low Calcium Type F flyash to the anhydrite was investigated.

Section II: Pack design criteria were developed for the introduction of anhydrite packs into the Lingan Colliery, Cape Breton Development Corporation, Sydney, Nova Scotia. This design was based on the Roof-Strata-Tilt method. Insitu plate-bearing tests were conducted in Lingan Colliery and intact tests were performed on floor rock materials for input data to this pack design method. A pack dimension is proposed and an insitu instrumentation program is recommended to monitor the performance of anhydrite packs during underground trials at Lingan Colliery.

Section III: The testing of anhydrite for use in the production of plasters was conducted using a finely ground anhydrite powder prepared using anhydrite obtained from Little Narrows Gypsum Co. Ltd. Accelerators and water combinations were determined that produced an anhydrite plaster with a Vicat set time very similar to the set time for 'stucco' (calcined gypsum or "hemihydrate")

used in the manufacture of gypsum wallboard ('drywall'). Efforts to produce an aerated plaster, using technology from the gypsum wallboard industry, were not successful. Test boards (40cmx 30 cm) of anhydrite were prepared which demonstrated that the anhydrite plaster developed a bond with the samples of paper currently used in the wallboard industry. The potential to use anhydrite as a plaster material for building construction materials and for floor screeds was advanced and continued testing is recommended.

Sommaire Executif

Quantité mineur de anhydrite ($CaSO_4$) sont produit annuellement en Nouvelle Écosse de (+95% $CaSO_4$) anhydrite dépôt du haut qualité sont estimer de contenir des billions de tonnes de cette resource. Certaines anhydrites quant écraser et combiner avec de l'eau et les chemiques accelerateur necessaire developerait dans une material cimenterie qu'aurait des applications industriel. Usage potentiel d'anhydrite était identifier comme des remblais de matérial de construction dans les mines charbon souterrain (cette pratique est utiliser présentment en Europe) et dans la production de plâtre d'anhydrite pour l'application dans la plaque de plâtre manufacturier (remplacer le gypse calciner où hémihydrate) et les préparations matériel de ragréyage pour les plancher.

Section 1: Exemple d'anhydrite étaient accumuler de quatre producteur gypse de Nouvelle Écosse. Des testes de laboratoire étaient accompli en utilisant une rangée de grandeur de produit d'anhydrite écraser, l'eau/soldes propertion et une variété de chemique accelerateur pour identifier les propriété mécanique de la gypse "sécher". Ces essais ont identifier que le anhydrite de Georgia Pacific Corporation ne possède pas les caractéristiques adéquat du cement pour être d'intérêt ulterieur dans cette investigation. L'anhydrite de Fundy Gypsum Co. Ltd. et National Gypsum (Canada) Ltd. démontre des propriété marginalment acceptable pendant que le Little Narrows Co. Ltd. anhydrite

indiquait potentiel excellent d'être utiliser comme des materiel "remblais" mine, materiels de construction dans les mines de charbon. Analyse macroscopique et microscopique de les materiels anhydrite étaient accompli et des differences cristallin que pourrait expliquer la variation dans la performance de ces materiels anhydrite sont discuter. Une extension de les tests mécanique de la Little Narrows Co. Ltd. anhydrite était faites pour determiner le optimum mélange d'anhydrite, accélérateur, et l'eau pour le mine des "remblais " application. L'affectation avantageux d'ajouter Bas Calcium Type F cendre volante à l'anhydrite était rechercher.

Section 11: Le critère de design des remblais ont été développer pour l'introduction d'anhydrite dans le Lingan Colliery, Cape Breton Development Corporation, Sydney, Nouvelle Écosse. Ce dessin a été fonder sur le méthode Roof-Strata-Tilt. In situ plaque portante tests on été conduit a Lingan Colliery et les tests intact ont été fait sur les matériel pour données d'entrée sur cet méthode remblais conception. Un remblis dimension) et proposé et un programme d'instrumentation et recommender pour moniter le performance des remblais d'anhydrite durant les essais souterrain à Lingan Colliery.

Section 111: Les testes d'anhydrite pour l'usage dans le production de plâtre ont été conduit en utilisant la poudre d'anhydrite finement moulager préparer usant l'anhydrite procurer

de Little Narrows Gypsum Co. Ltd. (Des combinations des accélérateurs et d'eau ont déterminer, qu'on produit un plâtre d'anhydrite avec un temps fixe Vicat semblable à le temps fixe pour de "stucage "(gypse calciner ou "hémihydrate") utiliser dans le fabrication de le plaque de plâtre de gypse (`mur de pierres sèches'). L'efforts pour produire un plâtre gazeuse, avec l'utilization technologique de l'industrie de plaque de plâtre de gypse, n'était pas une succès. La plaque d'essai (40 cm X 30 cm) d'anhydrite ont été preparé, qui indique que le plâtre anhydrite à développer un unité avec les examples de papier présentment utiliser dans l'industrie de la plaque de plâtre. La potentiel en utilisant comme la matériel de plâtre pour les matériel de construction pour des bâtisement et pour les étage matériel de ragréyage était avancer et le continuation des testes à été recommander.

PREFACE

Abundant quantities of gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$) occur together in evaporite deposits throughout Nova Scotia. In 1985, gypsum was produced by six mine operators in Nova Scotia with a total production of 5.9 million tonnes (6.5 million tons) or approximately C$42 of production value (NSDME, 1986). This 1985 production volume represents 75% of Canadian production and 7.3% of world production (80.9 million tonnes) (Raskill, 1987).

The anhydrite zones in these evaporite deposits do not generate a similar level of economic activity. Limited quantities of Nova Scotia anhydrite are produced for the cement manufacturing and agricultural industries. In 1985, anhydrite production amounted to 200,000 tonnes (NSDME, 1986). Gypsum producers will often mine 'around' anhydrite or mine it as a waste product to access gypsum for commercial value.

Uses for anhydrite have been identified as the following:

- as a construction material in coal mines mainly for roof support,
- for limited manufacture of plaster and floor screeds,
- as an inert filler,
- to produce elemental sulphur or sulphuric acid,
- as a nutrient and soil conditioner for the agricultural industry,

- in the glass manufacturing industry as a refining agent in place of sodium sulphate.

A research program was initiated under the Canada - Nova Scotia Mineral Development Agreement (MDA I) and administered by the Canada Centre for Mineral and Energy Technology (CANMET), to evaluate the material characteristics of Nova Scotia anhydrites. The investigator was awarded a research contract under the auspices of CANMET through the Department of Supply and Services (DSS Contract No. 23440-7-9035/01ST) to investigated the potential use of anhydrite i the following applications:

- as a construction material in coal mines,
- preliminary assessment of the potential to use anhydrite to manufacture plasters.

This report document is presented in three sections to reflect the diverse topics that were evaluated in this contract:

SECTION I - ANHYDRITE MATERIAL PROPERTIES INVESTIGATION FOR THE USE OF ANHYDRITE AS A CEMENTITIOUS CONSTRUCTION MATERIAL IN UNDERGROUND COAL MINES.

SECTION II - ANHYDRITE PACK DESIGN CRITERIA FOR LINGAN COLLIERY, SYDNEY, NOVA SCOTIA.

SECTION III - ANHYDRITE PLASTER INVESTIGATION.

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SECTION II

ANHYDRITE PACK DESIGN CRITERIA

FOR LINGAN COLLIERY, SYDNEY, NOVA SCOTIA

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ANHYDRITE MATERIAL PROPERTIES INVESTIGATION FOR THE USE OF ANHYDRITE AS A CEMENTITIOUS CONSTRUCTION MATERIAL IN UNDERGROUND COAL MINES

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September, 1989

1. APPLICATION OF ANHYDRITE IN UNDERGROUND COAL MINES

Anhydrite is a cementitious construction material used in underground coal mines for the following applications.

- gateroad pack construction in longwall mining,
- roadway backfilling,
- cavity filling on the face,
- construction of stoppings,
- roadway floor repair.

A brief description of these applications is provided in the following Section 1.1 of this report. This information is an overview of the subject matter and is included for the reader who is not familiar with coal mining technology. The descriptions are not to be considered a comprehensive or technical review of the subject matter and the reader who is familiar with coal mining technology is advised to proceed to Section 2 of this report.

1.1 Anhydrite Pack Construction Material

Longwall mining is a high volume, low cost underground method of extracting coal. During this mining activity large panels of coal (up to 300 m wide, 2500 m long and the thickness of the coal seam usually 1.5 to 10 m) are extracted by specialized longwall

mining machines. As a consequence of this coal extraction process the rock strata overlying the mined-out panel is left unsupported and collapses under its own gravitational load, Figure 1.1. The caving action will progress upward into the overlying strata until the void created by the coal removal has been filled with caved rock material (referred to as "gob" or "goaf"). The height of the cave zone is estimated to be 2 to 5 times the extraction height. The strata which lies above the cave zone will subsequently deflect downward, without fracturing, due to a lack of support. The phenomenon is referred to as subsidence and is shown in Figure 1.1. The subsidence of strata overlying the cave zone generates high stress conditions around the mining panel in the form of pressure abutments, Figure 1.2. The impact of these pressure abutments on the mine structure is outlined in the following paragraphs using examples of two longwall mining techniques, advance longwall and retreat longwall.

1.1.1 Packs in Advance Longwall

Advance longwall mining is practiced by development of panel access gateroads concurrent with the coal extraction on the longwall face. The face and gateroads are simultaneously "advanced" away from the main access roadways toward the end of the panel, Figure 1.3.

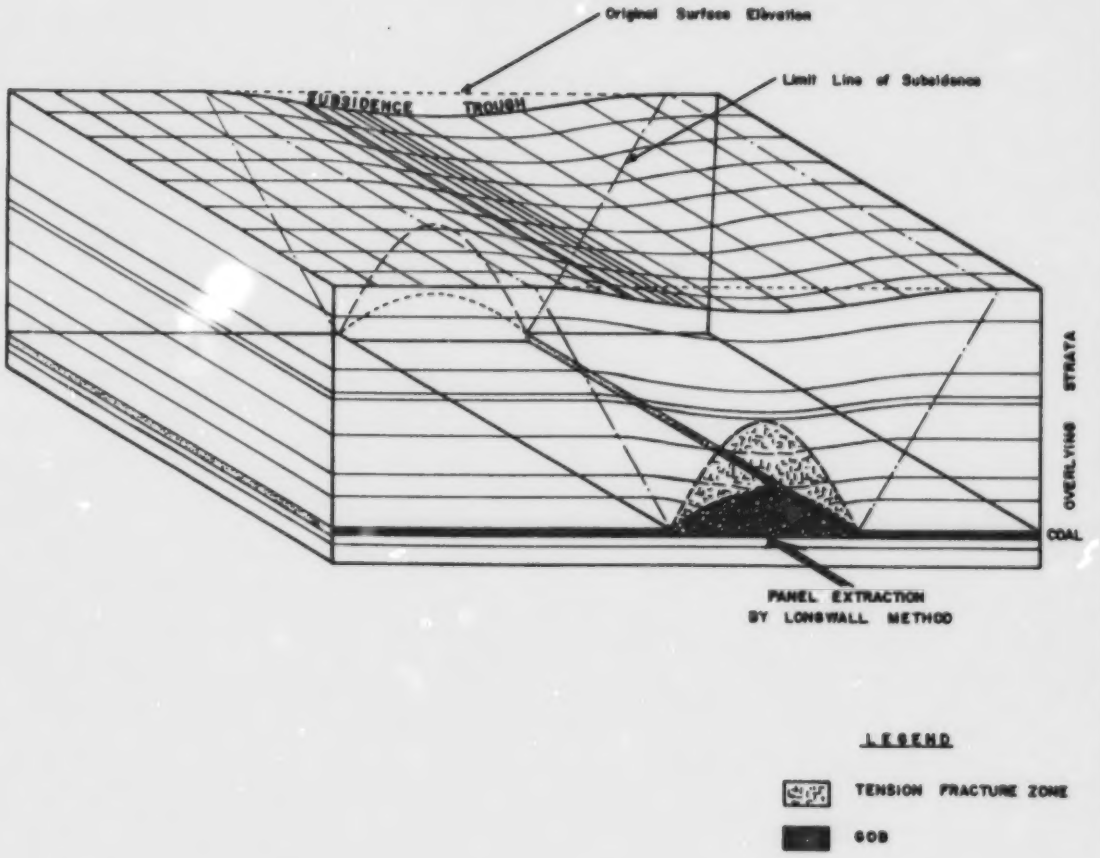


FIGURE H Schematic View of Longwall Mining System

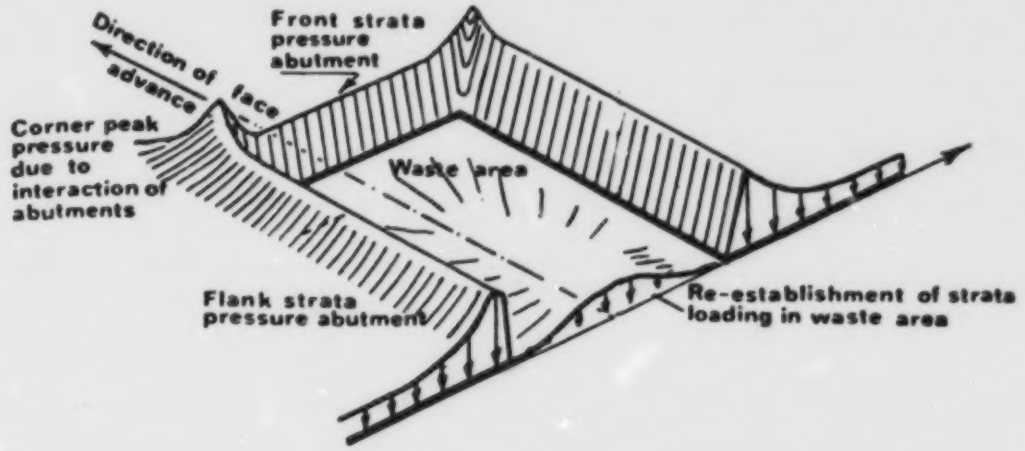

Direction of advance
Front strata pressure abutment
face
Corner peak pressure due to interaction of abutments
Waste area
Flank strata pressure abutment
Re-establishment of strata loading in waste area

FIGURE 1·2 Pressure Abutments Around A Longwall (Advance Longwall System Illustrated) (Peng , 1978)

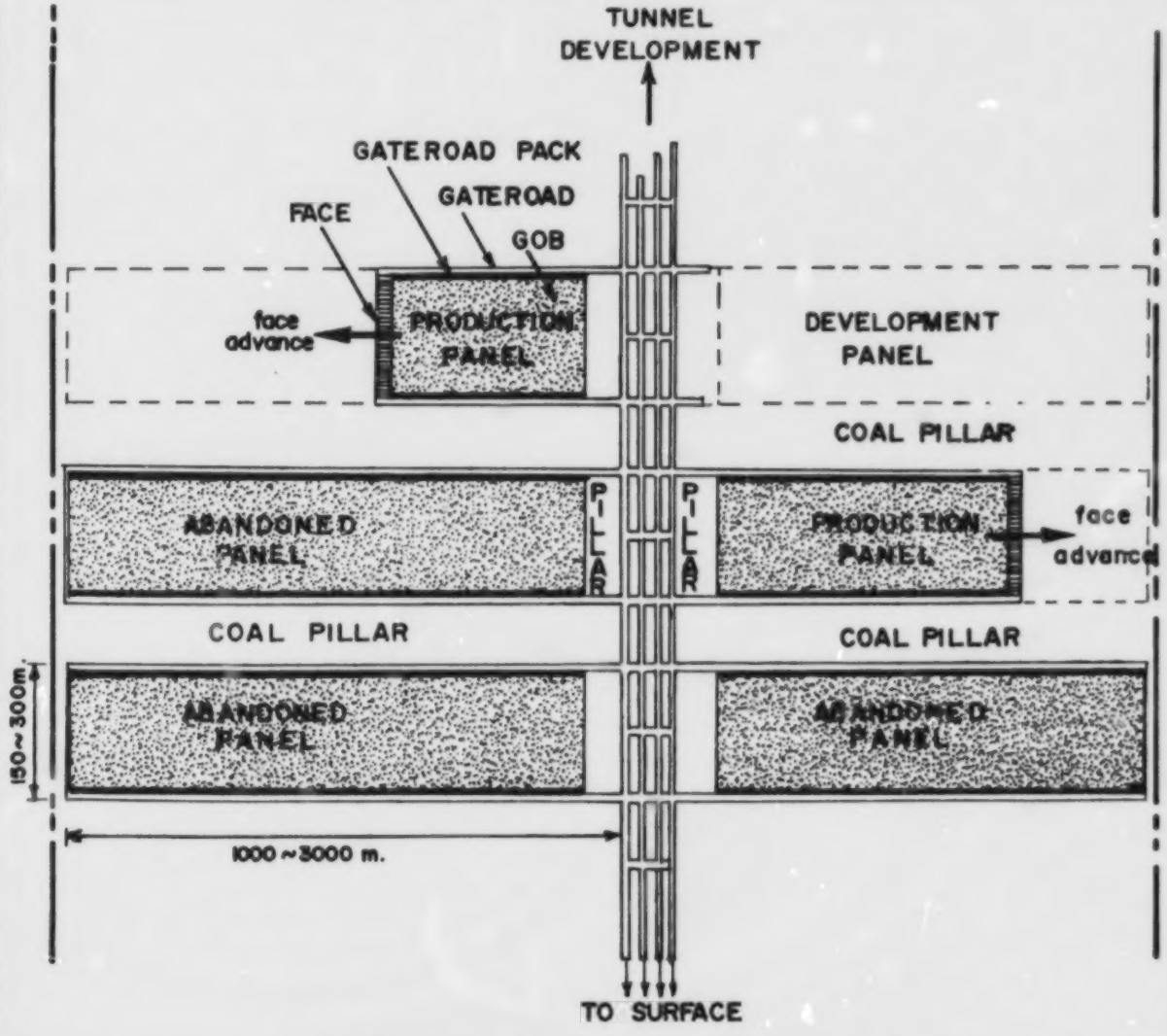


FIGURE 1·3 Plan View of ADVANCE LONGWALL SYSTEM

As a result of this mining sequence the gateroads are maintained in highly stressed ground next to the gob-area and are subject to severe deformation. In an effort to mitigate the effects of pressure abutments on the gateroad supports (usually steel arches), load bearing structures (referred to as "packs") are constructed on the gob-side of the gateroad. These packs are intended to replace the extracted coal adjacent to the gateroad and provide a support element that will resist the downward movement of the roof strata around the gateroad. The additional support provided by the pack prevents excessive deformation of the gateroad steel arch supports, Figure 1.4.

Two theories have been developed to permit the calculation of gateroad support loading and the determination of pack dimensioning criteria for longwall mining. These theories are:

- Detached Roof Block Theory - Figure 1.4(a), Whittaker, Woodrow; 1977)
- Roof Strata Tilt Theory - Figure 1.4(b), Smart, et al., 1984)

1.1.2 Packs in Retreat Longwall

Retreat longwall mining is practiced by development of panel access gateroads the full length of the panel and then mining the longwall face in a " retreat" direction toward the main access roadways, Figure 1.5. The gateroads are allowed to collapse with

the gob as they are not used in any subsequent mining activity. As a result of this mining sequence the active gateroads are always surrounded by unmined coal and are not subjected to the high stress conditions that were described in advance longwall. (Note: this discussion does not consider retreat longwall with a bleeder entry system, where packs are constructed as a normal practice to protect the gateroad for ventilation purposes during the life of the panel, Figure 1.6).

A system of retreat longwall mining where the gateroads are subject to high stress conditions is "pillarless retreat longwall", Figure 1.7. In this method sequential panels are mined without leaving coal pillars between the panels. In pillarless retreat longwall, gateroads are maintained in high pressure abutment zones next to the gob of an extracted panel by constructing a pack at the gob-side of the gateroad. This protected gateroad is then reused to extract the second panel by retreat method. As the second panel is extracted, the reused gateroad and pack collapse in the gob. This sequence of events is repeated to extract the coal seam without pillars of coal resource being left between the longwall panels. This method of extraction provides increased recovery of the coal resource by eliminating the requirements for barrier pillars between subsequent panels.

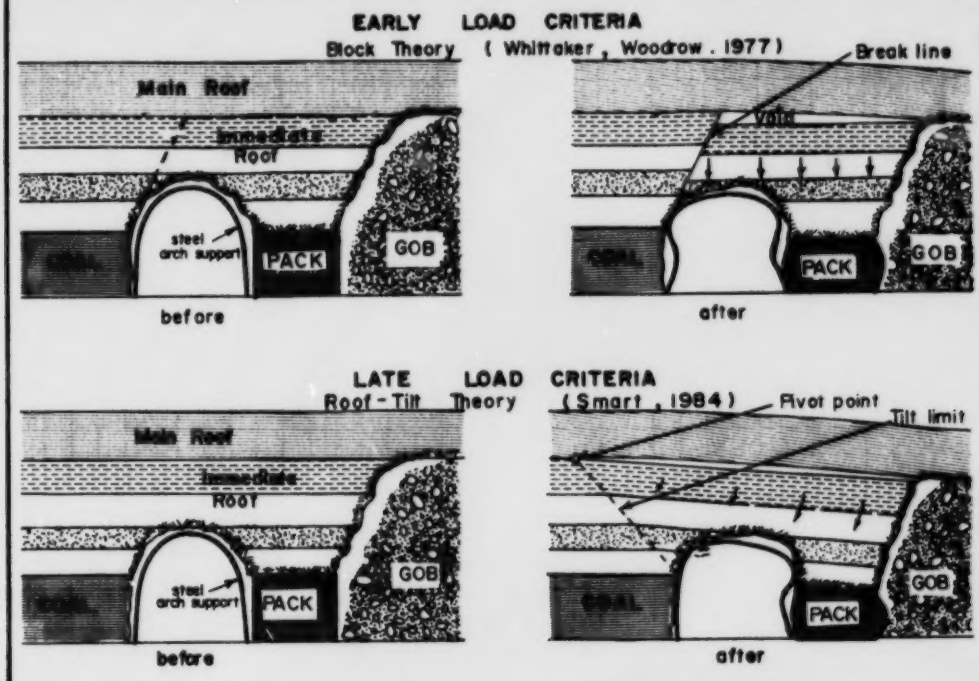


FIGURE 1-4 Illustration of Gateroad Steel Arch Deformation in Advance Longwall Mining

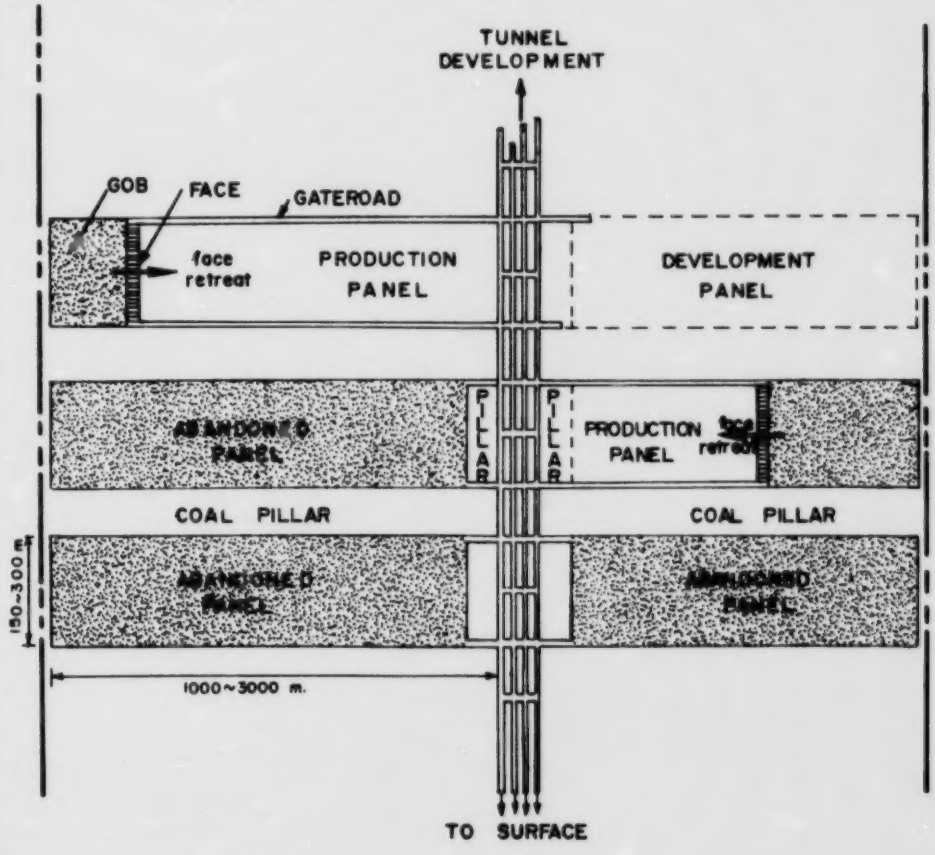


FIGURE 1-5 Plan View of RETREAT LONGWALL SYSTEM

1.1.3 Pack Construction Materials

A wide variety of materials have been used for longwall pack construction, as follows:

- wood timbers,
- hand and machine stowed rock walls,
- precast cement blocks (Aglite, Siporex and Celcon Block),
- cement based monolithic pumped packs (Aquapak, Astrapak, Tekpak),
- anhydrite packs.

An account of these alternative systems is not included in this report; however, the reader is referred to an excellent CANMET report by Cain, 1985 for further details.

The strength of each of these packing systems is illustrated in Figure 1.8 (Blades and Daws, 1974). It is observed that the high strength materials are wood and anhydrite. Wood was historically preferred as a pack construction material in coal mines because it was easily and safely cut to specifications in the mine and could be placed by hand. Also wood packs respond to strata loading conditions by gradually yielding and crushing without development of sufficient stored energy that would generate catastrophic failure. Anhydrite materials when strained display rapid strength development to ultimate compressive strength; however, following this upper limit anhydrite packs demonstrate

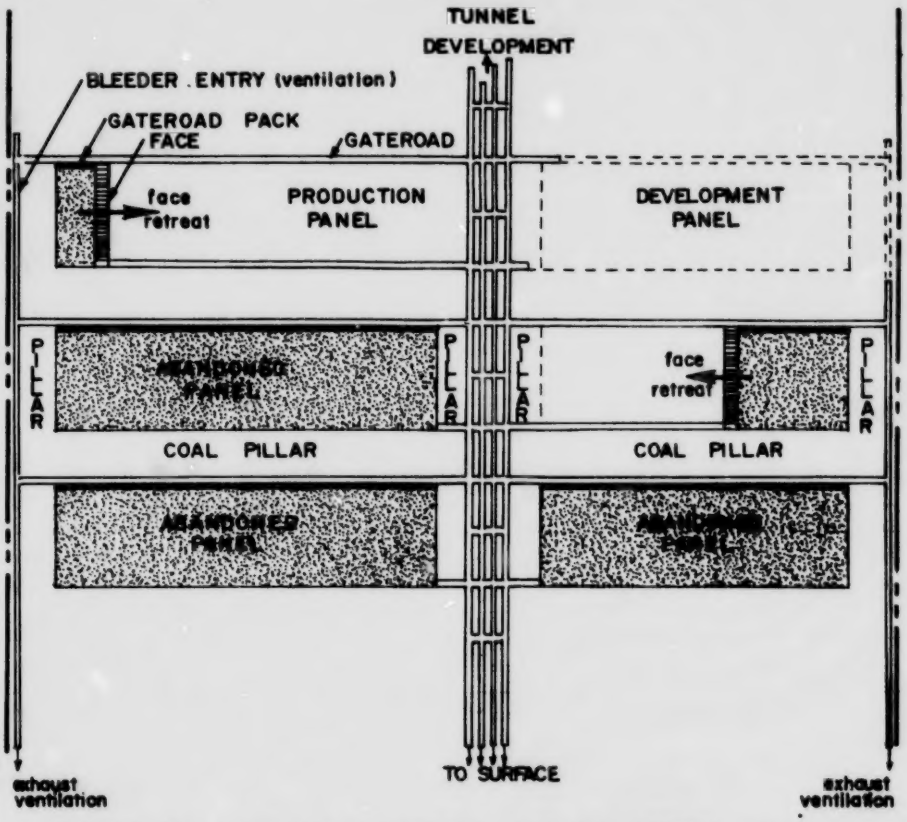


FIGURE 1·6 Plan View of RETREAT LONGWALL SYSTEM with Bleeder Entry System Ventilation

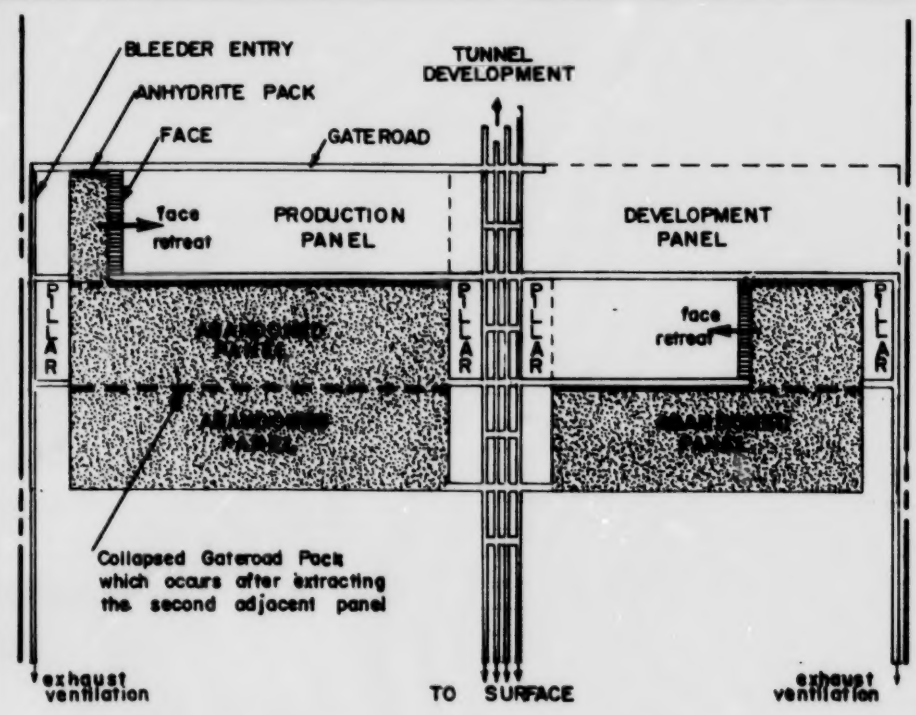


FIGURE 1·7 Plan View of PILLARLESS RETREAT LONGWALL SYSTEM

long term, high value post-failure strength that makes it suitable for pack construction work. Anhydrite is considered to be superior to wood as a pack construction material for several reasons:

1. the large volume of wood required for packs constitutes a major fuel load in the event of a mine fire and therefore is a hazard within the mine environment.

2. the placement of anhydrite packs is much less labor intensive than the manual construction of wooden packs; however, this advantage is somewhat offset by the requirement for substantial capital investment in anhydrite conveyance systems and pneumatic stowing equipment.

3. anhydrite packs should be lower cost (material and labor) than all the alternative packing systems, if a local source of anhydrite is available (Blades and Daws, 1974).

4. anhydrite packs seal the gateroad from the gob and prevent the leakage of ventilation air through the gob area that occurs when wood packs are employed, Figure 1.9. Ventilation leakage through the gob is a major problem especially in 'mature' advance longwall operations. Cement based monolithic pump pack systems also prevent ventilation leakage; however, these systems have much lower uniaxial

compressive strength and do not generate the support strength provided by anhydrite packs.

5. due to their increased load bearing capacity, anhydrite packs will greatly reduce the high cost for repair to roadway arch support that is experienced when wood packs are used.

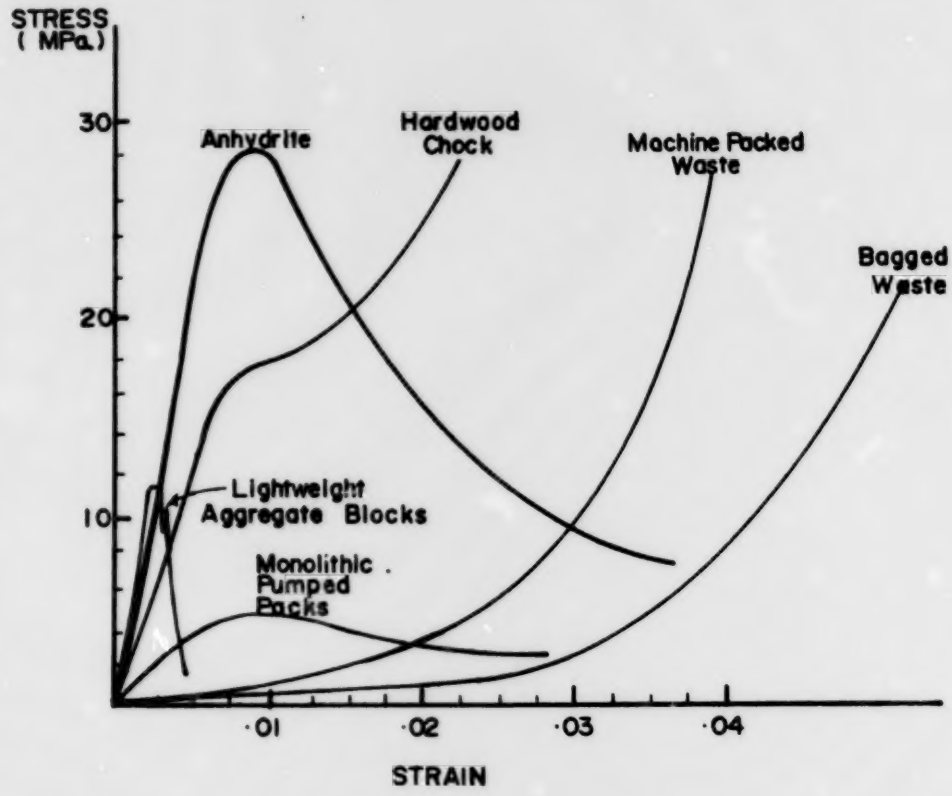


FIGURE 1·8 Uniaxial Compressive Strength of Alternative Mine Pack Construction Materials (Blades & Daws, 1974)

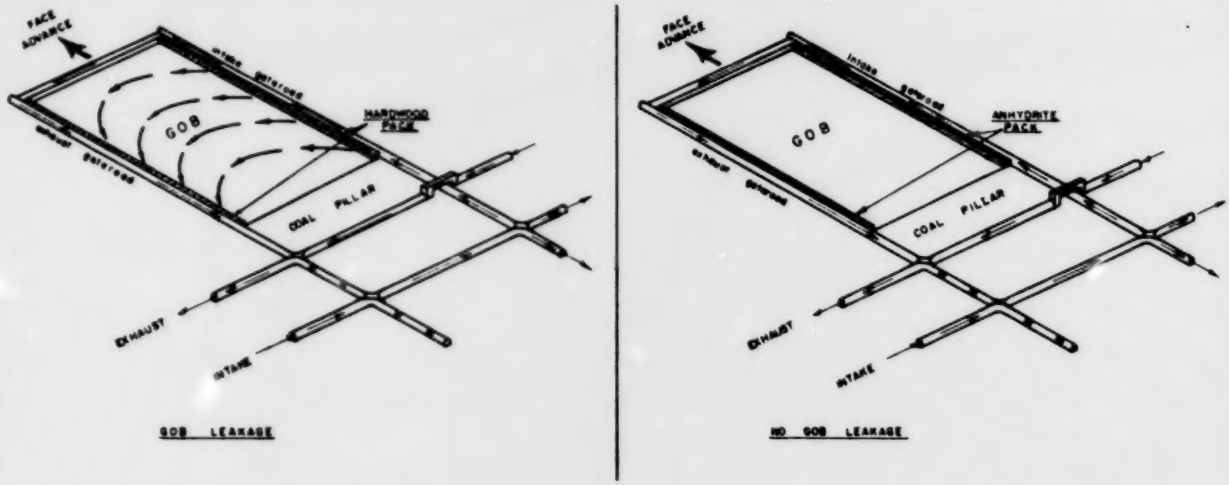


FIGURE 1·9 Leakage of Ventilation Air Through The Gob When Wood Is Used as a Pack Construction Material

1.2 Roadway Backfilling with Anhydrite

Steel arch structures are used extensively to support coal mine roadways and gateroads. Maximum strength of an arch support is achieved when the arch is in continuous contact with the rock strata behind the arch. Continuous contact is not normally achieved in coal mine gateroads as the access openings are mined to a size larger than the arch profile which is installed as the support member. The most common method of achieving this contact is by driving wooden wedges between the arch and the rock mass to provide blocking points for the arch, Figure 1.10. Close spacing of the blocking points is important to prevent excessive deformation of the support. This close spacing of blocking points requires stringent supervision by management and the availability of skilled arch-installation crews.

An alternative to point blocking is to use anhydrite to backfill behind the arch and provide a continuous blocking of the structure; Figure 1.11. Anhydrite backfilling requires that the arch be wrapped with a special wire mesh lagging mat to contain the anhydrite while it sets. Anhydrite has the consistency of a very thick "porridge" when placed and will not flow through the mesh of the lagging mat.

Portland cement based monolithic materials are available for backfilling behind mine arch supports; however, these systems require a more expensive, water tight continuous lagging over the arches to contain the fluid cementitious mixture while it sets. One system, Bullflex, uses a sausage-type plastic bag placed behind each arch support to contain the cement mixture. (The October, 1984 issue of Gluckauf is devoted to the topic of hydraulic, cementitious materials used in coal mines and is an excellent reference for this subject).

Portland cement based roadway backfill systems are placed independent of the pack construction activities. Conversely, anhydrite backfilling is practiced in conjunction with the pack construction activities in gateroads; Figure 1.11(c). The combined use of anhydrite pack construction and gateroad backfill work provides very competent gateroad structures that will experience limited deformation during the active life of the gateroad. In addition to improved gateroad conditions, the improved strength of fully blocked arch structures usually permits increased spacing of arch supports or the use of a reduced weight arch support member. These situations generate economic benefits to the mining operation.

1.3 Other Uses of Anhydrite in Underground Coal Mines

Several other limited uses of anhydrite are practiced in European coal mines are as follows:

- roadway floor repair work,
- construction of stoppings.

These anhydrite products differ from the anhydrite pack construction material only in the size distribution of the crushed anhydrite material. As the volume of anhydrite used in these applications is very small no attempt was made to evaluate these products in this investigation.

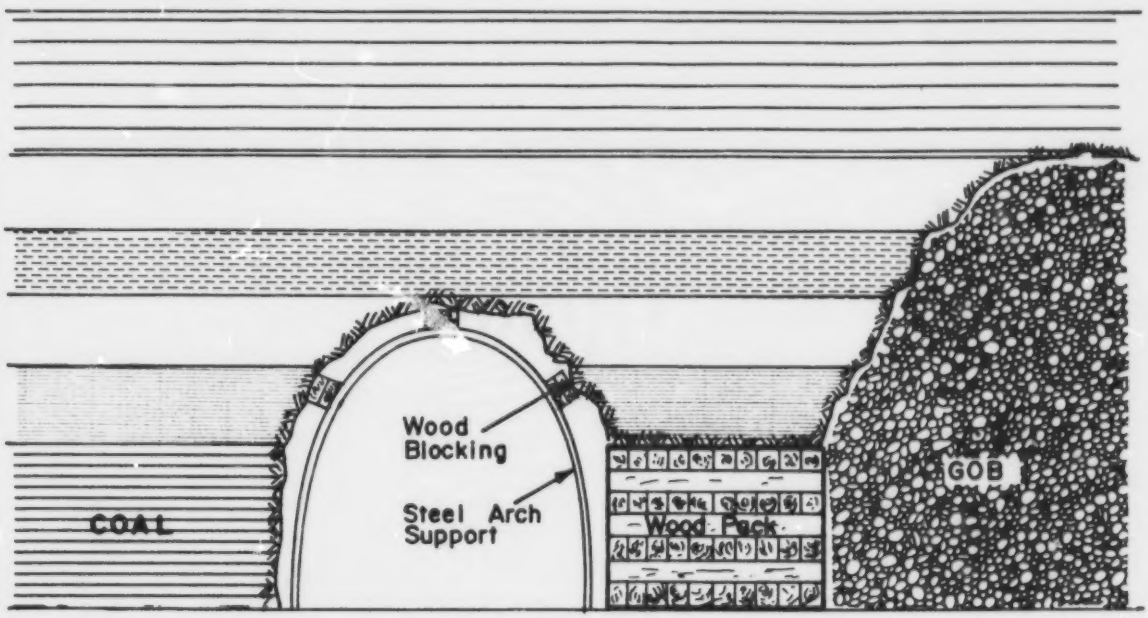


FIGURE 1-10 Blocking of a Gateroad Steel Arch Support in Longwall Mining

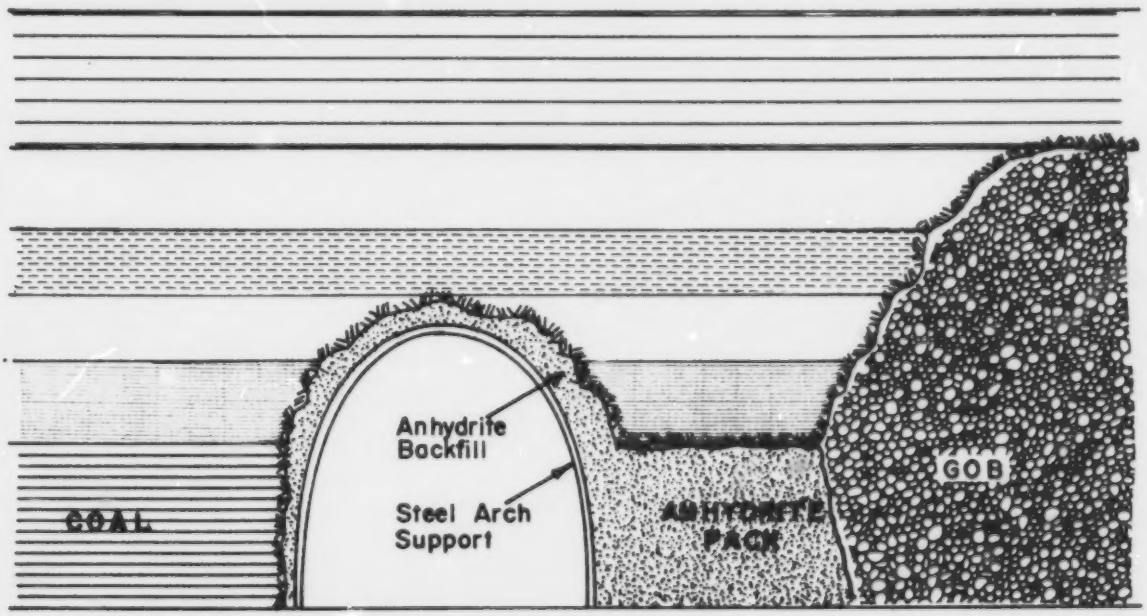


FIGURE 1-11 ANHYDRITE Backfill Behind Gateroad Steel Arch Supports

2. ANHYDRITE BASED MATERIALS USED IN UNDERGROUND COAL MINES

The use of anhydrite in underground coal mines is practiced extensively in West Germany and to a lesser degree in Great Britain and France. Several million tonnes of anhydrite are consumed annually for pack construction, roadway backfilling, etc. in coal mines. Commercial production of anhydrite in these countries is done by private companies, several of which are outlined in Table 2.1.

TABLE 2.1

MANUFACTURES OF ANHYDRITE CONSTRUCTION MATERIALS FOR COAL MINES

COUNTRY	MANUFACTURER	PRODUCT
West Germany	Gebr. Knauf Westdeutsche Gepswerke	Knauf Anhydrite
Great Britain	British Gypsum Limited	ANPAK A,B,C
France	SMA	SMA Anhydrite

These companies produce a range of anhydrite products for different applications (Statham CA, 1987). For example, British Gypsum Limited produces three (3) products which are designated as follows: (British Gypsum, Technical Brochures)

ANPAK A - suitable for pumping equipment

ANPAK B - used with spraying equipment

ANPAK C - placed by pneumatic stowing equipment.

Anhydrite is commonly prepared for commercial use by dry crushing the run-of-mine anhydrite in an impact crusher equipped with specially sized grates and a dust collection system. This crushed product is then transported by bulk carriers to the mine site. The anhydrite is taken underground either by a batch system (rail cars) or a centralized pneumatic transportation system following which it is stored in underground storage bins. A pneumatic stowing is used to blow the anhydrite through wear resistant pipes to the application site (packhole). At the packhole the anhydrite is pneumatically forced through a special mixing nozzle where it is dampened with water at a rate of 8% to 10% by weight of the anhydrite. An accelerator is also added to the anhydrite - water mixture. This accelerator consists of 1.8 parts of ferrous sulphate heptahydrate ($FeSO_4.7H_20$) and 1 part potassium sulphate (K_2SO_4) at a concentration of between 1 and 2% by weight of the anhydrite (Arioglu and Dunham, 1976; Blades and Daws, 1974). There are 3 methods of introducing the accelerator into the anhydrite water mixture:

- the accelerator can be mechanically mixed with the anhydrite at the manufacturers plant before delivery to the mine,
- the accelerator can be stored in a separate hopper on the pneumatic stowing machine and be metered by an auger type feeder into the dry anhydrite as the anhydrite is blown by the pneumatic stowing machine

into the conveyance pipes for placement in the packhole,

- the accelerator can be mixed with the water in an agitator type mix tank underground and pumped to the packhole at the time of usage where the water-accelerator solution is mixed with the dry anhydrite through a special mixing nozzle.

The extensive use of cementitious construction materials, including anhydrite, in European coal mines has led to the development of a strength criteria for mine pack and backfill materials (Arauner H. W. 1984) as shown in Figure 2.1. This designation is used in West Germany and adopted in other European Counties as a valid criteria for evaluating construction materials for coal mines. An overlay has been prepared for Figure 2.1 to show the range of Figure 2.1 strengths for commercial products "KNAUF" and ANPAK" as published in technical brochures by the manufactures of these products.

The criteria for backfill and pack construction material outlined here will be referenced throughout the remainder of this report.

2.1 Anhydrite Materials

Extensive work has been conducted world-wide to define phases of the $CaSO_4$-H_2O system and to outline the characteristics

of each phase. Generally accepted principles of the system are described by Wirsching, 1978. In this detailed work, 5 phases of the system are identified and natural anhydrite is restricted to the Anhydrite II-S phase as shown by the asterisk in Table 2.2. The conversion of anhydrite II-s to gypsum proceeds directly and does not go through the intermediate phases of anhydrite III or hemihydrate. This reaction follows a process as outlined in Figure 2.2. The multi-stage process from anhydrite II-s to dihydrate follow the laws of seeding and crystal growth as discussed by Wirsching. The reaction is exothermic and the heat of hydration liberated during the process is outlined in Table 2.3.

Based on this information it is concluded that all the work conducted on Nova Scotia anhydrites in this contract will be restricted to the anhydrite II-s phase and that the reactions will be exothermic in nature.

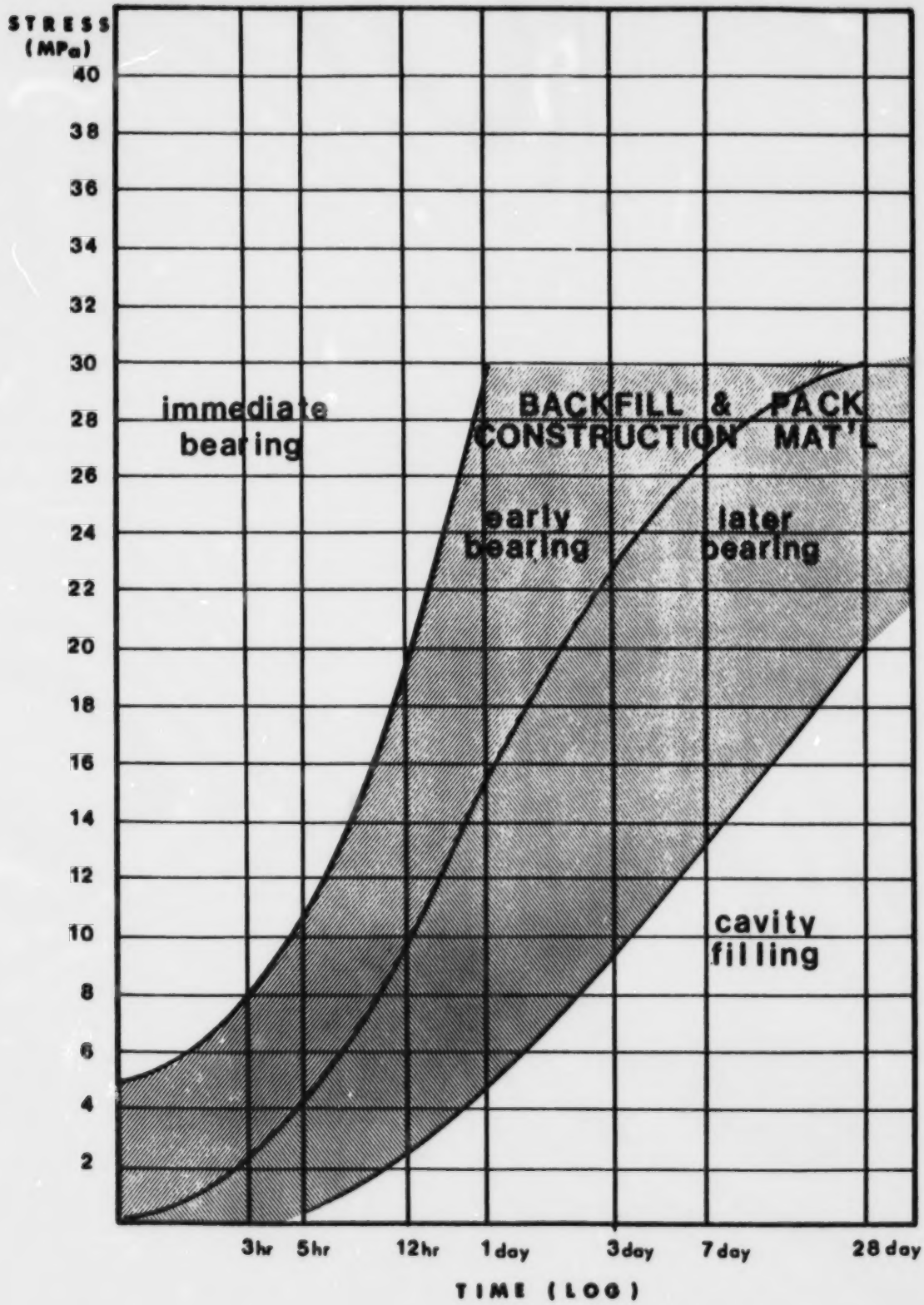


Figure 2.1 Strength Criterion For Cementitious Construction Materials Used in Underground Coal Mines.

Table 2.2 Characteristics of the Phases of the $CaSO_4$-H_2O System

Chemical formula of the phase	$CaSO_4 \cdot 2H_2O$	$CaSO_4 \cdot \frac{1}{2}H_2O$		$CaSO_4$ III	$CaSO_4$ II	$CaSO_4$ I
1. Features		2 Forms: β-form	α-form	3 stages: β-Anhydrite III, β-Anhydrite III', α-Anhydrite III	3 stages of reaction of calcined anhydrite II: A II-s slowly soluble Anhydrite, A II-u insoluble Anhydrite, A II-E Estrichgips	
2. Description of phase	Calcium sulphate dihydrate	Calcium sulphate hemihydrate		Anhydrite III	Anhydrite II	Anhydrite I
3. Further description	Gypsum, raw gypsum; synthetic gypsum, chemical gypsum, by-product gypsum; set and hardened gypsum	β-hemihydrate, stucco plaster, β-plaster	α-hemihydrate, autoclave-plaster, α-plaster	soluble anhydrite	raw anhydrite, natural anhydrite, anhydrite; synthetic anhydrite, chemical anhydrite; by-product anhydrite, calcined anhydrite	high temperature anhydrite
4. Water of crystallisation (Combined water) (% weight)	20.92	6.21	6.21	0.00	0.00	0.00
5. Density (g/cm³)	2.31	2.619 – 2.637	2.757	2.580	2.93 – 2.97	Not determined
6. Molecular weight	172.17	145.15	145.15	136.14	136.14	136.14
7. Lattice structure	Monoclinic	rhombohedral		hexagonal	rhombic	cubic
8. Hardness (Mohs)	1.5	–	–	–	3 – 4	–
9. Solubility in water at 20°C (g/100 g solution)	0.21	0.88	0.67	as hemihydrate	(0.27)	–
10. Refractive indices n_α n_β n_γ	1.521 1.523 1.530	1.559*) 1.5595*) 1.584	1.559*) 1.5595*) 1.584	1.581 1.581 1.546	1.570 1.576 1.614	Not determined Not determined Not determined
11. Optical character	+			+	+	Not determined
12. Optical orientation	$n_\beta \| b$ $n_{\gamma'} = 52$	$c \| n_\gamma$	$c \| n_\gamma$	$c \| n_\gamma$	$n_\gamma \| c$ $n_\beta \| c$	Not determined
13. Axialangle 2 V	58 – 60	14	14	almost 0	42 – 44	Not determined
14. Space group	$C2/c = C^6_{2h}$	$C3_12 = D^4_3$	$C3_12 = D^4_3$	$C6_32 = D^4_6$	$Cmm = D^{17}_{2h}$	Not determined
15. Lattice spacing nm a b c	1.047 1.515 0.628	0.683 0.683 1.270		0.699 0.699 0.634	0.696 0.695 0.621	Not determined Not determined Not determined
16. Thermodynamic stability (°C)	< 40	metastable		metastable	40 – 1180	> 1180
17. Production temperature in laboratory (°C)	< 40	45 – 200 in dry air	> 45 in aqueous medium	50 Vacuum, 100 Air, 100 dry β-AIII } α- and β-AIII	200 – 1180	> 1180 and stable below
18. Production temperature in industry (°C)	< 40	120 – 180	80 – 180	290 β-AIII, 290 β-AIII', 110 α-AIII	between 300 – 900: < 500: AII-s, 500 – 700: AII-u, > 700: AII-E	–

Table 2.3 Heat of Hydration of the Technically Important Reactions of the $CaSO_4$-H_2O System

Phase	Form	Reaction	Heat of Hydration at 25 °C (J/mol)	(KJ/Kg Dehydrate)
Hemihydrate	β	$CaSO_4 \cdot \frac{1}{2}H_2O + 1\frac{1}{2}H_2O$ fl. = $CaSO_4 \cdot 2H_2O$	19 300 ± 85	111.9 ± 0.50
Hemihydrate	α	$CaSO_4 \cdot \frac{1}{2}H_2O + 1\frac{1}{2}H_2O$ fl. = $CaSO_4 \cdot 2H_2O$	17 200 ± 85	100.00 ± 0.50
Anhydrite III	β	$CaSO_4 + 2H_2O$ fl. + $CaSO_4 \cdot 2H_2O$	30 200 ± 85	175.3 ± 0.25
Anhydrite III	α	$CaSO_4 + 2H_2O$ fl. + $CaSO_4 \cdot 2H_2O$	25 700 ± 85	149.6 ± 0.50
Anhydrite II		$CaSO_4 + 2H_2O$ fl. + $CaSO_4 \cdot 2H_2O$	16 900 ± 85	98.0 ± 0.50

fl.: liquid

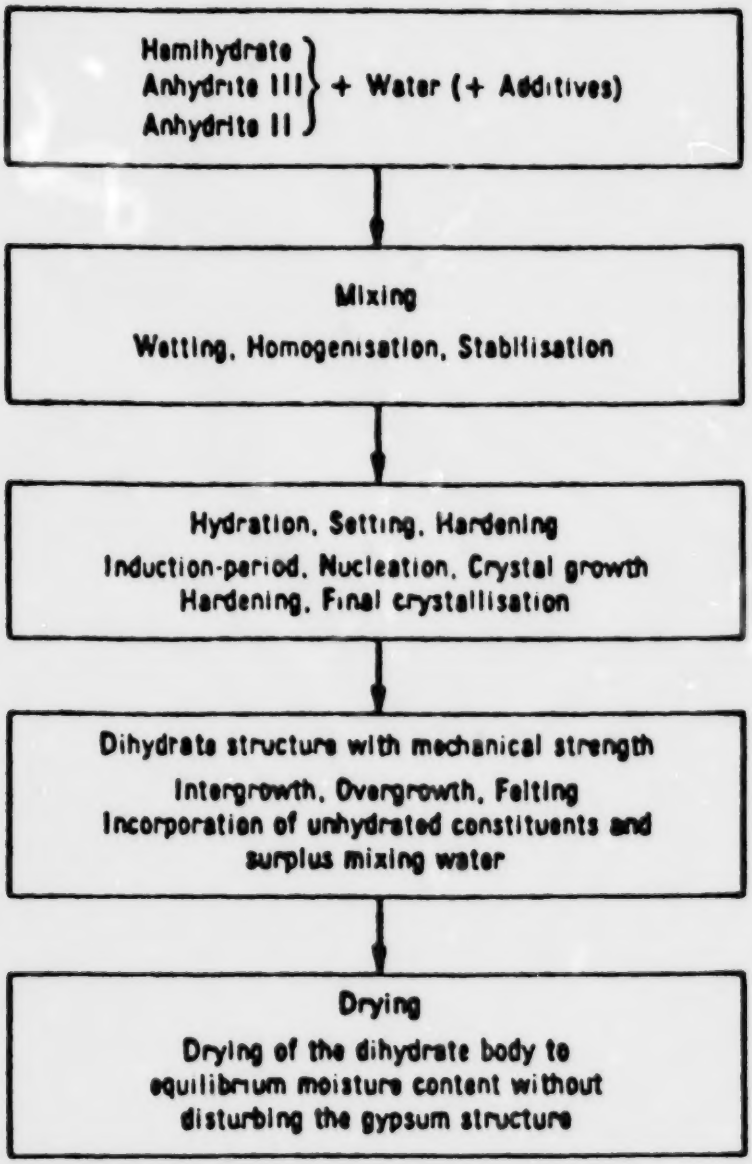


Figure 2.2 Stages of Hydration, Setting and Hardening of Calcium Sulphates.

3. ANHYDRITE MATERIAL TEST PROCEDURES

All anhydrite deposits are not suitable to manufacture anhydrite materials for use in coal mines. Testing is required on individual deposits to determine the material characteristics of the reconstituted anhydrite product. Consequently, a program of testing the readily accessible anhydrite deposits in Nova Scotia was initiated to determine if these anhydrites are suitable for coal mine applications. Gypsum producers in Nova Scotia extract a limited amount of anhydrite for the agricultural industry and cement manufacturing industry. One tonne samples of anhydrite were collected from each of the following mines for testing:

- Little Narrows Gypsum Company Ltd. (LN), Little Narrows, Victoria County
- Fundy Gypsum Company Ltd (FG), Windsor, Hants County
- Georgia Pacific Corporation (GP), River Denys, Inverness County.

Tests were also conducted on anhydrite from National Gypsum (Canada) Ltd. (NG) at the end of this investigation. National Gypsum does not currently produce anhydrite for commercial markets but provided a sample of material to be tested. Results on the National Gypsum anhydrite are included in this report even though these tests were limited.

The anhydrite was hand picked, high grade samples however the mine geologists at each site considered the samples to be representative of the insitu anhydrite deposits. It was the opinion of the mine manager at each site that large quantities of high-grade anhydrite could be mined for commercial use if the markets existed to support production.

3.1 Testing Standards

Laboratory strength testing of anhydrite materials was limited to uniaxial compression tests which accurately represent the insitu loading conditions for anhydrite pack structures in coal mines. There are no established standards found in either:

- ASTM (American Standards for Testing of Materials),
- CSA (Canadian Standards Association)
- ISRM (International Society of Rock Mechanics)

to control test procedures for anhydrite materials. The most extensive experience in testing anhydrite materials is found in West Germany at the national building materials test centre, Bergbau-Forschung GmbH. This centre provides testing and research laboratories for all construction materials in West Germany, and anhydrite testing constitutes only a very minor component of the centre. A technology transfer trip to Bergbau-Forshung GmbH was funded under this project to observe anhydrite testing procedures used at the test centre. Reference is made

throughout this report to the practices and procedures that were adopted from these observations.

Bergbau-Forschung GmbH also provides a service to companies preparing anhydrite for commercial use. The centre receives samples of anhydrite material crushed at industrial plants and conducts mechanical strength tests on specimens prepared from the anhydrite material. The results from these tests are supplied to the producers for quality control purposes. The centre also conducts industrial research for producers and users of anhydrite materials.

3.2 Variables to be Controlled During Tests

At the outset of this investigation it was recognized that a large number of variables existed that could effect the laboratory test results. The major variables which were identified are as follows:

- anhydrite material differences,
- particle size effect,
- water to solids ratio,
- type and quantity of accelerator,
- cure time,
- cure environment,
- test specimen size.

Preliminary tests were conducted with Nova Scotia anhydrite materials and one proprietary mix of anhydrite pack construction

material, product "K" from Europe, to evaluate the significance of these variables. European anhydrite materials, product "K" and product "A", are referenced in this report for comparison with product sizing, mechanical strength values and chemical composition of Nova Scotia anhydrite materials.

3.3 Anhydrite Material Analysis

Representative samples of the three Nova Scotia anhydrite materials and one European proprietary anhydrite pack construction material were analyzed, using a whole-rock analysis technique, to determine the composition of these materials. The results of these analyses are shown in Table 3.1:

Table 3.1
Analysis of Anhydrite Material

Analysis	Composition (%)			
	Little Narrows	Fundy Gypsum	Georgia Pacific	Product[1] "K"
Moisture	0.01	0.06	0.05	0.22
Combined Water	0.42	1.31	0.84	0.61
SO_3	57.51	57.62	58.41	53.49
CaO	41.22	40.39	40.92	38.50
Fe_2O_3	0.10	0.07	0.06	0.48
K_2O	-	-	-	0.48
SiO_2	0.17	0.13	0.29	1.25
Al_2O_3	0.11	0.12	0.11	0.81
MgO	0.10	0.05	0.01	1.44
Gypsum	2.00	6.26	4.01	2.91
Anhydrite	96.20	93.02	96.14	88.65
$CaCO_3$	1.67	0.05	0.01	1.84
NaCl	0.01	0.01	0.02	0.14

1 Product "K" is a commercially available proprietary anhydrite pack construction material used in European coal mines.

Some of the observations that were made based on this analysis are as follows:

- the commercially available product "K" contained a lower percent anhydrite (88.65%) than existed in the Nova Scotia anhydrite samples (93 to 96%). It is likely that this low % anhydrite was due to additives that were used to manufacture product "K" (discussed below).
- the quantity of gypsum in product "K" and Little Narrows materials (2 to 3%) was lower than the gypsum in Georgia Pacific (4%) and Fundy Gypsum (6%) materials.
- the Nova Scotia anhydrites had less than 0.1% potassium (K) and iron (Fe) while product "K" had approximately 0.5% of each. This result is generated because product "K" had an accelerator mixture of K_2SO_4 and $FeSO_4.7H_2O$ blended with the anhydrite material for commercial use.
- there are high values of SiO_2, Al_2O_3, MgO in product "K" when compared with the Nova Scotia anhydrite materials. These materials could come from several sources as follows:
  - clay minerals that were mined as impurities with the anhydrite.
  - the presence of dolomite/limestone mined with the anhydrite.
  - the blending of an additive with the anhydrite to

produce product "K". It is known that European producers add fly ash to certain anhydrite products. The presence of SiO_2, Al_2O_3 and MgO support this fact; however, no conclusion could be made without additional mineralogical analysis.

- the amount of salt (NaCl) present in the product "K" (0.14%) was significantly larger than was present in the Nova Scotia anhydrites (0.01% to 0.02%). Salt is an accelerator in the hydration reaction of anhydrite to gypsum. The salt in product "K" could have been added during its manufacture or it could have been present in the mined anhydrite product.
- the amount of $CaCO_3$ present in product "K" and the Little Narrows product (1.67%) were similar and much larger than was found in the Georgia Pacific (0.01%) or Fundy Gypsum (0.05%) anhydrite materials.

It was concluded from these analyses that significant differences existed in the anhydrite materials tested. No attempt was made to affect any change in the chemical composition of the test materials; however the effects of additives such as fly ash were tested to evaluate the potential for a "low cost" replacement material in Nova Scotia anhydrite products. The whole-rock analysis was conducted to provide information to

explain test result variations for the different anhydrite materials.

3.4 Anhydrite Material Preparation

The Nova Scotia anhydrite samples were crushed at the Minerals Engineering Center, Technical University of Nova Scotia. A combination of two jaw crushers and one cone crusher were used in this dry comminution process. The crushed anhydrite was dry screened using a Gilson vibrating screen deck to produce a sized product for subsequent blending. These product sizes were selected to correspond with product sizes identified in two European proprietary anhydrite pack construction materials, product "K" and product "A".

Table 3.2

Sizes of Screened Products of Anhydrite Material

Size (mm)	Mesh Designation	
	Cdn and USA	Tyler
+8.00mm	+5/16"	+ 2 1/2mesh
-8.00 + 4.75mm	-5/16" + 4mesh	- 2 1/2 + 4mesh
-4.75 + 2.36mm	-4 + 8mesh	- 4 + 8mesh
-2.36 + 0.60mm	-8 + 30mesh	- 8 + 28mesh
-600 + 212 micron	-30 + 70mesh	- 28 + 65mesh
-212 + 150 micron	-70 + 100mesh	- 65 + 100mesh
-150 + 75 micron	-100 + 200mesh	- 100 + 200mesh
-75 micron	- 200mesh	- 200 mesh

The screened products were stored in separate air-tight containers to prevent possible natural hydration of the anhydrite material.

The preparation of anhydrite at Bergbau-Forschung GmbH is accomplished using a laboratory impact crusher equipped with sizing grates and dust collection equipment (dust product put back in crushed material) to generate the desired size distribution of anhydrite particles in test specimens. An impact crusher was not available for this contract preparation work and consequently the process previously described was used.

3.5 Control of Test Variables During Specimen Preparation

The large number of variables that were defined in Section 3.2 obviated the requirement for standards to control sample preparation work. The lack of approved standards for these variables required that the investigators set reasonable standards for this test program. The remainder of this section of the report will discuss the standards that were determined for the test program.

3.5.1 Particle Size Effect

All test specimens of Nova Scotia anhydrite were prepared by combining predetermined quantities of each screened anhydrite product to generate an anhydrite mix of a specific size distribution.

Test specimens were prepared to parallel the size distribution of two European anhydrite pack constructions materials, products "A" and "K", as well as three other size

distributions (0%, 15% and 30% fines). It is emphasized that the major difference in each of these products is the amount of (-75 micron) fines materials in the test specimen. The size distributions for Nova Scotia anhydrite specimens tested in this investigation are outlined in Table 3.3.

A size analysis for the fine fraction, (-75 micron) of each anhydrite material was conducted using a Malvern Instruments, Laser Size Analyzer. The results are shown in Table 3.4 and are plotted in Figure 3.1.

The information shows that the fines (-75 micron) fraction of each product tested (product "K", Little Narrow, Fundy Gypsum, and Georgia Pacific) were similar. It was anticipated that the slight variation in the size distribution of the fines would not cause large variations in the test results.

The size analysis of the fines material (-75 micron) is introduced at this stage of the report because the effect of fine grinding on high early strength development will be discussed later in this report.

3.5.2 Water: Solids Ratio

The literature review demonstrated that the maximum strength anhydrite product was achieved with a water content of 8.5% by

Table 3.3
Size Distribution by Weight of
Nova Scotia Anhydrite Test Specimens

Size	% Composition									
	Product "K" Simulation		Product "A" Simulation		0% Fines[1]		15% Fines[1]		30% Fines[1]	
	%	Cum %	%	Cum %	%	Cum %	%	Cum %	%	Cum %
+ 8 mm	1.2	100.0	0.3	100.0	0.4	100.0	0.3	100.0	0.2	100.0
- 8 mm + 4.75 mm	5.0	98.8	16.1	99.7	21.4	99.6	18.2	99.7	15.0	99.8
- 4.75 mm + 2.36 mm	20.6	93.8	11.3	83.6	15.0	78.2	12.8	81.5	10.5	84.8
- 2.36 mm + 600 m	33.3	73.2	28.8	72.3	38.2	63.2	32.5	68.7	26.8	74.3
- 600 m + 212 m	11.7	40.0	10.3	43.5	13.7	25.0	11.6	36.2	9.6	47.5
- 212 m + 150 m	2.5	28.3	2.4	33.2	3.2	11.3	2.7	24.6	2.2	37.9
- 150 m + 75 m	4.1	25.8	6.1	30.8	8.1	8.1	6.9	21.9	5.7	35.7
- 75 m	21.7	21.7	24.7	24.7	0.0	0.0	15.0	15.0	30.0	30.0

[1]Note: The 0%, 15%, 30% Fines Products were based on the 24.7% Fines, product "A" size distribution.

Table 3.4
Size Distribution by Weight of The (-75 m) Fines

Size (micron)	Product "K"		Little Narrows		Fundy Gypsum		National Gypsum	
	%	Cum %	%	Cum %	%	Cum %	%	Cum %
180	-	-	0.2	100.0	-	-	1.7	100.0
150.0	0.4	100.0	0.4	99.8	-	-	3.5	98.3
125.0	3.1	99.6	0.7	99.4	1.9	100.0	9.1	94.8
90.0	3.7	96.5	1.1	98.8	2.8	98.1	5.5	85.7
75.0	5.2	92.8	3.1	97.6	4.4	95.3	5.5	80.2
63.0	14.7	87.6	12.4	94.5	14.1	90.9	11.8	74.7
45.0	17.4	72.9	17.9	82.1	17.2	76.7	14.6	62.8
32.0	15.7	55.5	17.4	64.2	15.6	59.6	14.6	48.3
22.6	13.9	39.8	17.4	46.9	15.9	44.0	12.3	33.6
16.0	9.6	25.9	11.5	29.6	10.6	28.1	8.6	21.3
11.3	5.5	16.3	6.5	18.1	6.2	17.5	4.7	12.7
8.0	4.4	10.7	5.5	11.6	5.4	11.2	2.9	8.0
5.7	2.5	6.3	2.6	6.1	2.8	5.9	2.2	5.0
4.0	1.3	3.8	1.1	3.5	1.2	3.1	1.4	2.9
2.8	1.1	2.5	0.9	2.4	0.7	1.8	0.7	1.5
2.0	0.4	1.4	0.4	1.5	0.3	1.0	0.2	0.7
1.7	0.4	1.0	0.4	1.1	0.3	0.7	0.2	0.5
Specific Area	0.08 m^2/cc		0.10 m^2/cc		0.09 m^2/cc		0.06 m^2/cc	

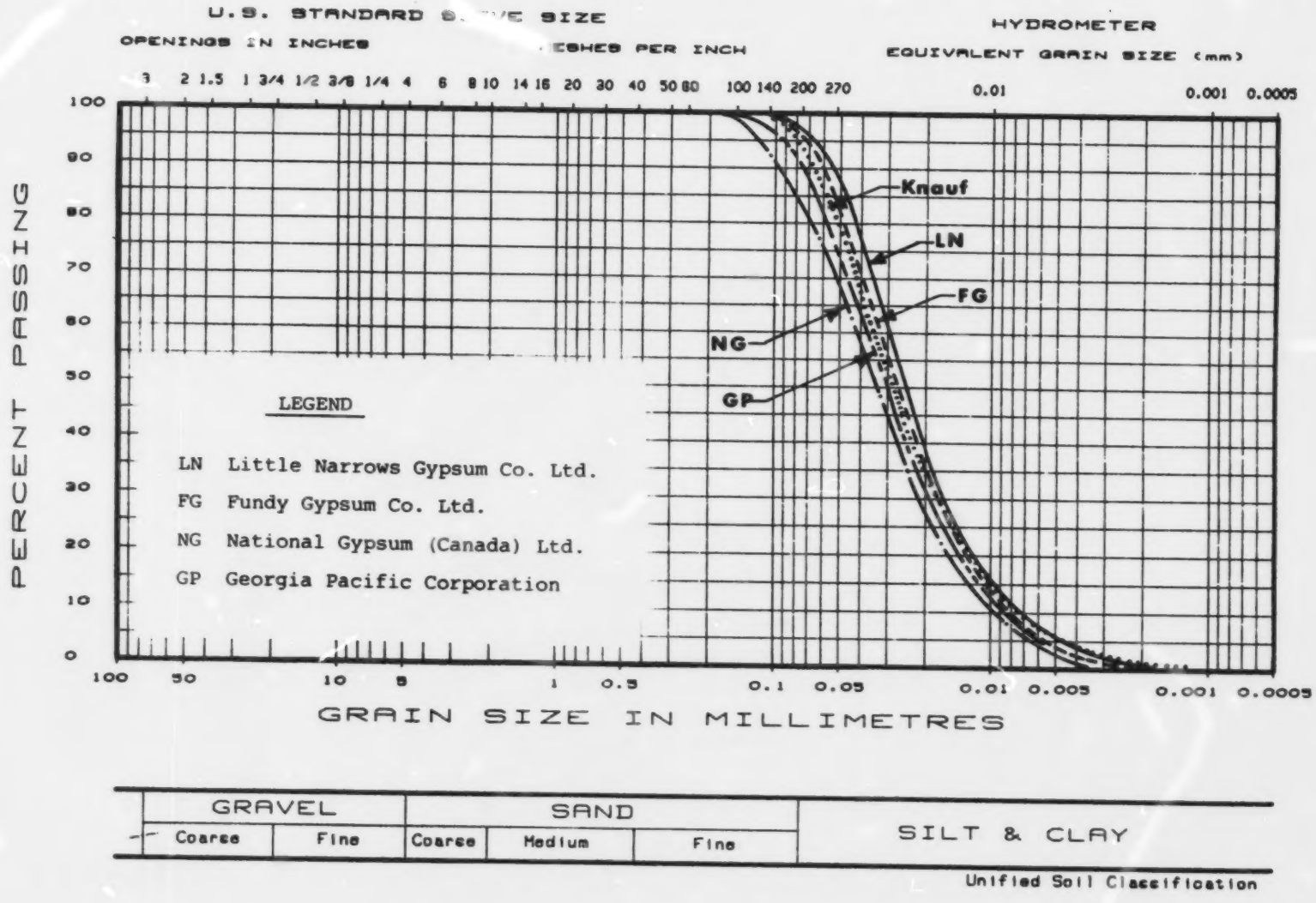


Figure 3.1 Size Distribution of the (-75 micron) Fines.

weight. A range of water contents were tested to determine the optimum water to solids ratio for Nova Scotia anhydrite.

The water used in all tests was Halifax tap water. The water was stored in a head tank at room temperature (70°F) for a least 24 hours prior to use. Water was carefully measured in a graduated cylinder and cross-checked by weight before it was mixed with the anhydrite.

3.5.3 Accelerator Type and Quantity

The standard accelerator used in European anhydrite pack construction material is a mixture of 1.8 parts iron sulphate heptahydrate ($FeSO_4.7H_2O$) and 1.0 part potassium sulphate (K_2SO_4). This accelerator mixture is used at a concentration of 1% to 2% of the anhydrite dry weight.

The investigation of Nova Scotia anhydrites concentrated on this accelerator mixture; however, variations in the amount of accelerator were tested. The accelerator quantities were accurately weighted at the time of the test. The accelerator was added to the mix water and stirred using a magnetic stirrer until it was dissolved. The water and accelerator solution was then mixed with the anhydrite. The decision was made to dissolve the accelerator in the mix water instead of dry mixing it with the anhydrite to ensure a homogeneous distribution of the accelerator throughout the anhydrite material. It is commented that both

dry-mix and wet-mix techniques are employed in anhydrite packing. Therefore the decision to dissolve the accelerator in the mix water is consistent with industrial practices. Limited testing of the dry-mix technique was conducted. The product "K" tested in this investigation contained a dry-mixed accelerator.

3.5.4 Cure Time

The anhydrite specimen strength development was monitored over a 7 day period at the following standard time intervals 3 hour, 5 hour, 12 hour, 24 hour, 3 days, 7 days. Efforts to conduct one hour tests were not successful due to insufficient set in the anhydrite to allow removal of the specimens from the mold. One hour tests were possible at later stages of this investigation when the early strength of the specimens were sufficiently high to allow separation from the molds.

3.5.5 Cure Environment

Preliminary evaluation was done using a cure environment that is specified for concrete in ASTM standards. Early test work was done by bagging all anhydrite specimens in sealed plastic bags at 70°F until test time.

The cure environment used at the Bergbau-Forschung GmbH test centre is the room atmosphere of the test laboratory. The

anhydrite specimens were cast in molds and released after "thumb-set" to air-dry. This practice was adopted for the majority of testing in this investigation. Due to the preliminary test work on sealing the specimens in plastic bags conclusions are made in this report regarding the effect of moisture on the strength development of anhydrite. At the completion of this test program a series of tests were conducted on the final anhydrite mix recommended by this investigation, to further evaluate the effect of humidity on the set characteristics.

3.5.6 Specimen Size and Shape

It was decided to form all preliminary tests specimens using standard cube molds prescribed in CSA and ASTM standards. Standard procedures for casting, tamping and levelling cube specimens were followed.

Anhydrite test specimen are prepared at Bergbau-Forshung GmbH using 40 mm x 40 mm x 160 mm triple-ganged molds. This configuration provided one bending tensile strength and two compressive strength tests for each specimen. At the West German test centre it was observed that the anhydrite mixture was hand-packed in the mold and then levelled using a steel bar. The anhydrite mixture was not tamped as is required by CSA, ASTM standards in cube tests. The following specimen sizes were tested in this investigation:

- 40 x 40 x 160 mm - tensile bending test
  - uniaxial compression test
- 101.6 mm cubes (4.0") - uniaxial compression test
- 50.8 mm cubes (2.0") - uniaxial compression test
- 203.2 mm cubes (8.0") - uniaxial compression test

The cube specimens were tamped according to CSA and ASTM standards while the 40 x 40 x 160 mm samples were hand-packed as observed at Bergbau-Forschung GmbH.

3.5.7 Test Apparatus

The equipment used to test specimens of anhydrite material are as follows:

Uniaxial Compression Tests:

2000KN Capacity ELE 2000 digital hydraulic Compression Frame - axial deformations were measured by a linear displacement transducer (LDT) monitoring the platen to platen distance on the machine.

Bending Tensile Tests:

3-point bend apparatus on a 10 TON Wykeham-Farrance mechanical test frame. Loads were determined using a 907 kgf (2000 pound) proving ring.

4. PRELIMINARY TEST RESULTS

At the start of the laboratory investigation, preliminary tests were conducted to determine the effect that test variables had on the mechanical properties of the cured anhydrite material The variables that were investigated are

- anhydrite material suitability,
- water content of the mix,
- cure environment,
- specimen size effect.

These variables were identified in the literature review or observed during the technology transfer trip to West Germany.

4.1 Suitability of Nova Scotia Anhydrite Materials

Investigations in Europe have demonstrated that some European anhydrite materials in the presence of a water/accelerator solution, do not hydrate rapidly enough to generate the high early strengths required for a pack construction material.

The first set of preliminary tests conducted on Nova Scotia anhydrites evaluated the early set characteristics using the following mix criteria:

. Size distribution - 20.7% fines

. Water content - 8.5%

. Accelerator - 1.0% of 1.8:1 ($FeSO_4.7H_2O:K_2SO_4$)

. Cure period - 1 day (24 hours).

Anhydrite materials from Little Narrow, Fundy Gypsum, and Georgia Pacific and the product "K" were tested. The specimens were tested in uniaxial compression and failed at the ultimate strength outlined in Table 4.1.

Table 4.1

Preliminary Ultimate Strengths of Anhydrite Specimens at 1-Day

Product	Ultimate Strength
product 'K'	15.9
Little Narrows	14.8
Fundy Gypsum	9.1
Georgia Pacific	2.6

The range of strength defined for anhydrite pack construction materials is 5 MPa to 16 MPa for a 1-day cure. It was concluded from this preliminary work that both Little Narrows and Fundy Gypsum materials warranted further investigation. The Georgia Pacific anhydrite did not develop adequate strength to satisfy the required criteria. Further preliminary testing on the Georgia Pacific anhydrite was conducted by varying the accelerator and water volumes. No positive results were determined from the additional testing and it was concluded that the Georgia Pacific material would be eliminated from further testing in this investigation.

4.2 Water Content Relationship

The literature review indicated that anhydrite mixes with a water content of 8.5% develop the highest uniaxial compressive strength (Arioglu E and Dunham R. K., 1976). Water contents of up to 10% are often used in practice to minimize dust generation during placement of anhydrite in the pack-hole. The effect of water volume on Nova Scotia anhydrite materials was evaluated in a series of preliminary tests. The product "K" was also evaluated for comparison. During these tests 1% accelerator by weight of the anhydrite was used which consisted of 1.8:1 ferrous sulphate heptahydrate; potassium sulphate. The information from these tests is shown in Figure 4.1. The tests on product "K" confirm the fact that the maximum strength was achieved at a water content of 8.5% by weight. The Fundy Gypsum anhydrite, with 24.7% fines, demonstrated a maximum strength at 8.25% water content. The Little Narrows material had maximum strengths at a water content ranging between 7.5% and 8.25% depending on the percent fines in the product.

Another observation on water content made from these preliminary tests was that the strength values for product "K" and Georgia Pacific anhydrites were more sensitive to water content than the Little Narrows products. This is concluded from the relative flatness of the curves for the Little Narrows products compared with the steeply inclined curves for product "K" and Fundy Gypsum anhydrites.

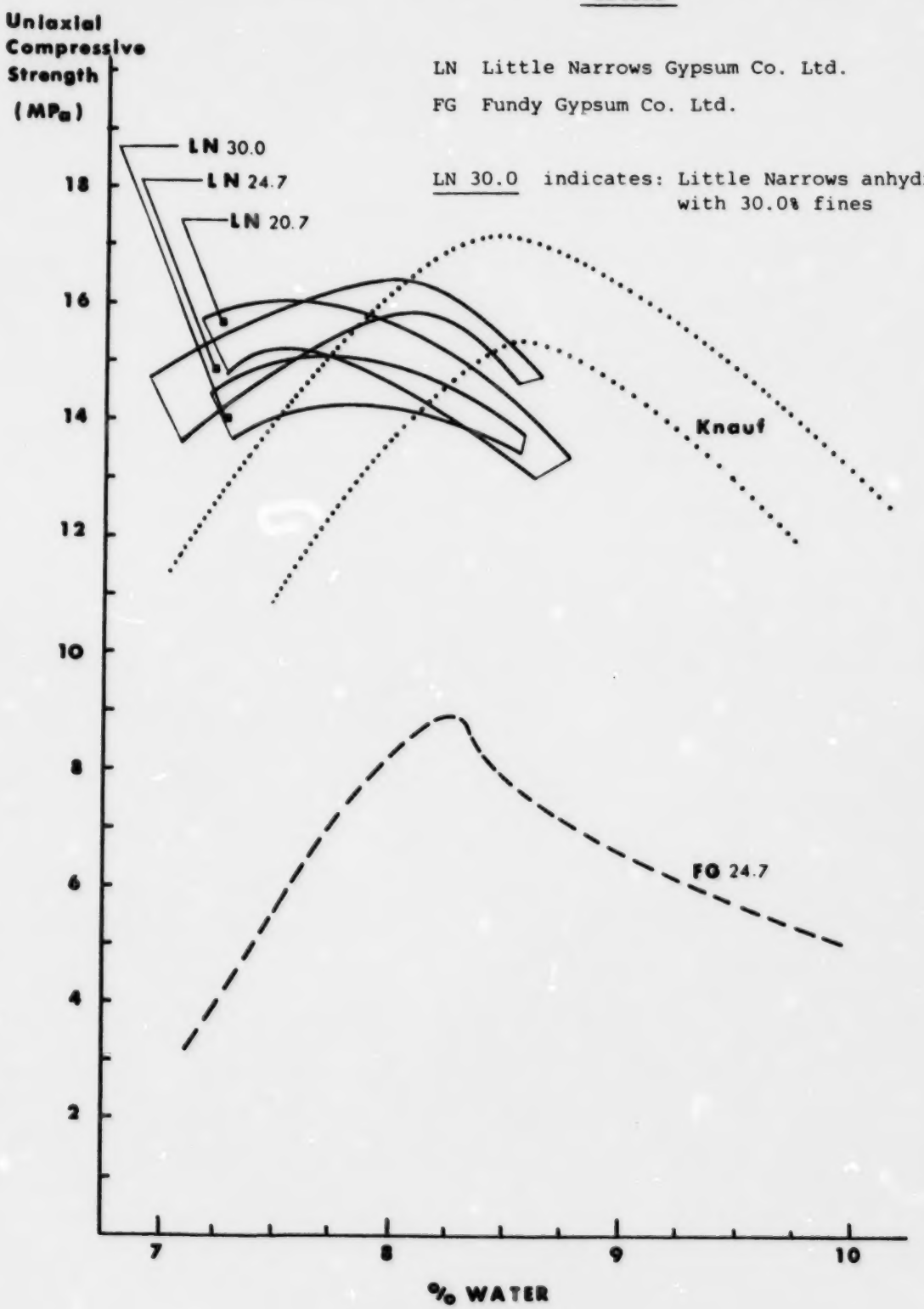


Figure 4.1 Effect of % Water on the Uniaxial Compressive Strength of 1-Day Cured Anhydrite Materials.

4.3 Cure Environment Relationship

Preliminary tests were conducted on product"K" anhydrite to examine the effect of humidity during curing on the mechanical strength development of the specimens. Identically prepared specimens were cured at room temperature in different humidity environments:

- tightly sealed @ 100% humidity
- air dried @ 25% humidity

The results of the uniaxial compression tests on these specimens at 5 hour cure time are shown in Table 4.2.

Table 4.2

EFFECT OF % HUMIDITY ON THE EARLY STRENGTH OF ANHYDRITE MATERIAL

CURE PERIOD	MATERIAL	UNIAXIAL COMPRESSIVE STRENGTH (MPA) air dried(25%)	sealed (100%)
5 Hours	product 'K'	1.4 MPa	0.7 MPa

It is noted that low-humidity promotes the development of high early strength in the product "K" anhydrite. Despite this fact, it was decided to conduct all final product tests with air-cured specimens. This practice is consistent with air-curing procedure conducted at Bergbau-Forshung GmbH in West Germany.

At the termination of the product testing, work was conducted to define the effect of humidity on a recommended mix of Nova Scotia anhydrite product. Description of this work is presented in Section 6.1.

4.4 Specimen Size Relationship

Construction materials such as concrete, mortar, etc, are tested at a standard specimen size because there is a size effect on the mechanical strength properties of these materials. It was observed at Bergbau-Forschung GmbH that anhydrite test specimens were cast in triple-ganged molds to yield test specimens 40 x 40 x 160 mm in size. Each specimen was first tested in a 3-point bend test apparatus and the two resultant 40 x 40 x 80 mm halves were then tested in uniaxial compression using 40 x 62.5 mm hardened steel platens. This test program was adopted for the Nova Scotia anhydrite testing, however tests were also performed on two other specimen sizes to predict a size effect on mechanical strength properties.

Test specimens were cast using the following parameters:

anhydrite - Little Narrows, 20.7% fines

accelerator - 1% @ 1.8:1 ($FeSO_4.7H_2O$: K_2SO_4)

water - 8.5%

The specimen sizes and the uniaxial compressive strength at 1-day cure time are shown in Table 4.3.

Table 4.3

Sample Size Effect on the 1-Day Uniaxial Compressive Strength of Little Narrows Anhydrite Material

Specimen Size (mm)	Surface Area (mm^2)	Uniaxial Compressive Strength (MPa)
40 x 62.5	2 500	13.5
101.6 x 101.6	10,323	10.1
203.2 x 203.2	41,290	9.1

It is noted that with increased specimen size there is a decrease in uniaxial compressive strength. This information is plotted in Figure 4.2. It is observed that the anhydrite specimen strength decreased asymptotically toward a constant value after the 203.2 x 203.2 mm specimen size. A projection is made in Figure 4.2 that establishes a relationship between the uniaxial compressive strength of a mine pack and the 40 x 62.5 mm specimen. This relationship is:

pack strength = 1/2 uniaxial compressive strength of the 40 x 62.5 mm laboratory specimen.

This rule-of-thumb relationship was confirmed by scientists at Bergbau-Forchung GmbH to be the same relationship used for anhydrite pack design work in West German coal mines.

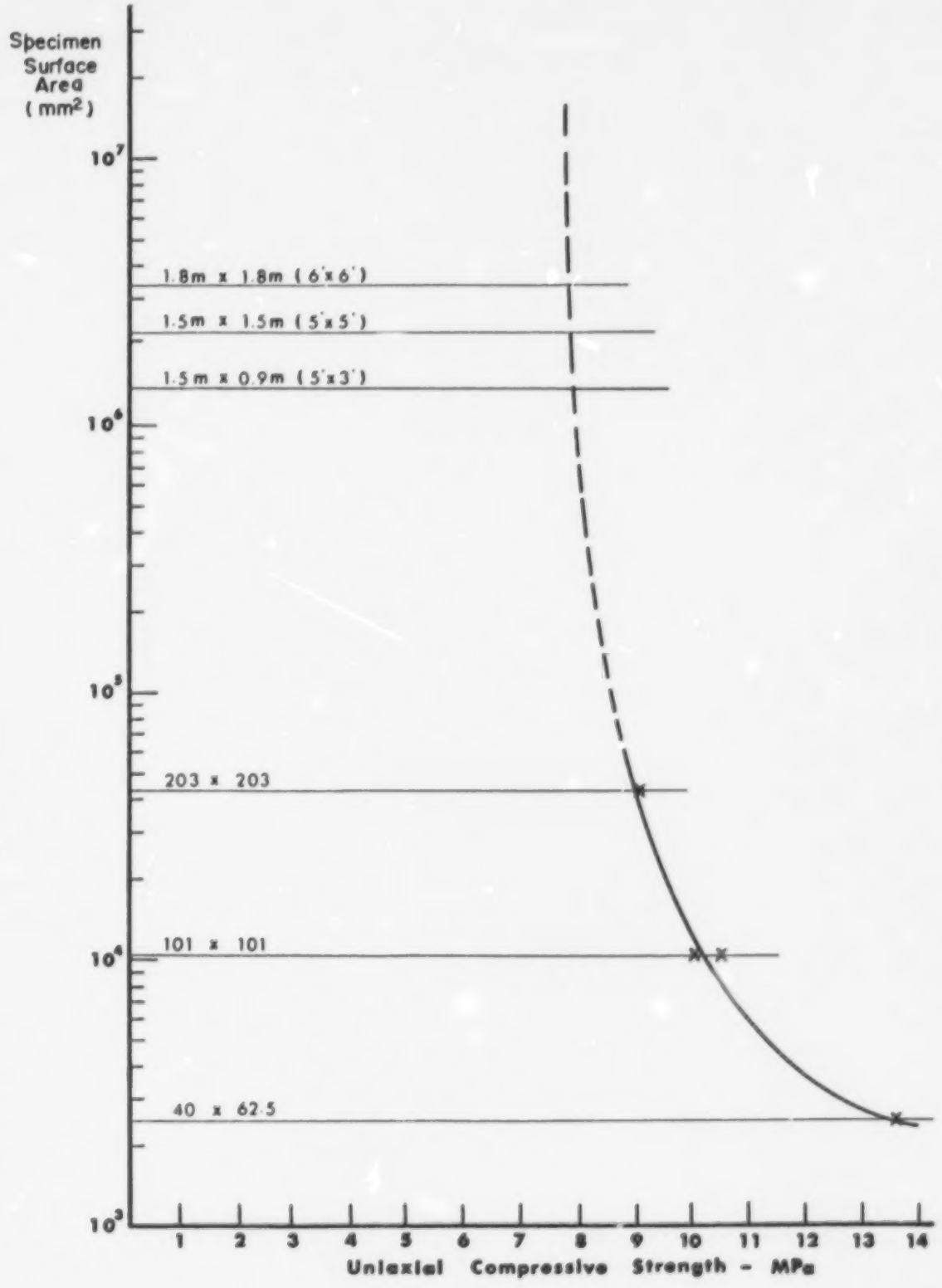


Figure 4.2 Sample Size Effect on the 1-Day Uniaxial Compressive Strength of Little Narrows Anhydrite Material.

5. DETAILED PRODUCT TESTS ON NOVA SCOTIA ANHYDRITES

Detailed mechanical strength tests were conducted on three Nova Scotia anhydrites (Little Narrows Gypsum Ltd, Fundy Gypsum Ltd and National Gypsum Canada Ltd) to examine the potential to use these materials for anhydrite packing in coal mines. Detailed tests were not done on the Georgia Pacific Corporation anhydrite samples as preliminary work demonstrated that it was not suitable as a pack construction material. Despite eliminating the Georgia Pacific material from detailed tests, analysis was conducted on the preliminary test specimens to evaluate why this material did not demonstrate the required cementitious properties. This information is presented in the Evaluation section of this report.

Detailed mechanical strength tests were conducted in three phases which were as follows:

- Standard Anhydrite Mixes
- Anhydrite Mixes with Finely Ground -75 micron Size Fraction
- Anhydrite Mixes with Fly Ash Addition

5.1 Standard Anhydrite Mixes

The preliminary tests discussed previously and the Standard Mix tests were conducted on anhydrite materials crushed using two jaw crushers and a cone crusher. The crushed product was screened and recombined in predetermined quantities to produce

anhydrite test specimens with the desired size distribution. The fines material (defined as the -75 micron size fraction) which comprised the Regular Mix is described in Section 3.4 of this report and detailed in Table 3.4 and Figure 3.1.

Uniaxial compressive strength tests were performed on 40 x 40 x 62.5 mm specimens at time intervals of 3 hr, 5 hr, 12 hr, 1 day, 3 days and 7 days. Longer term 28 day test results are not presented as the initial 7 days of strength development are most important for pack design work. The strength development history for each of Little Narrows, Fundy Gypsum and National Gypsum anhydrites with a Regular Mix composition are shown in Figure 5.1.

It is noted that slight variations in test parameters (eg: % water, % accelerator) between comparison products were small and did not significantly effect the tests results. The water and accelerator quantities were maintained within normal operating ranges for anhydrite:

water (8.0 to 10.0%)

Accelerator (1 to 2%)

The comparison overlay sheet in Figure 5.1 indicates that the Nova Scotia anhydrite materials have medium and late term compressive strengths that are suitable for use in pack construction work. However, the low early strength of the anhydrite mixes tested (at <5 hours) were not sufficient to provide the early resistance required for strata control in longwall gateroads.

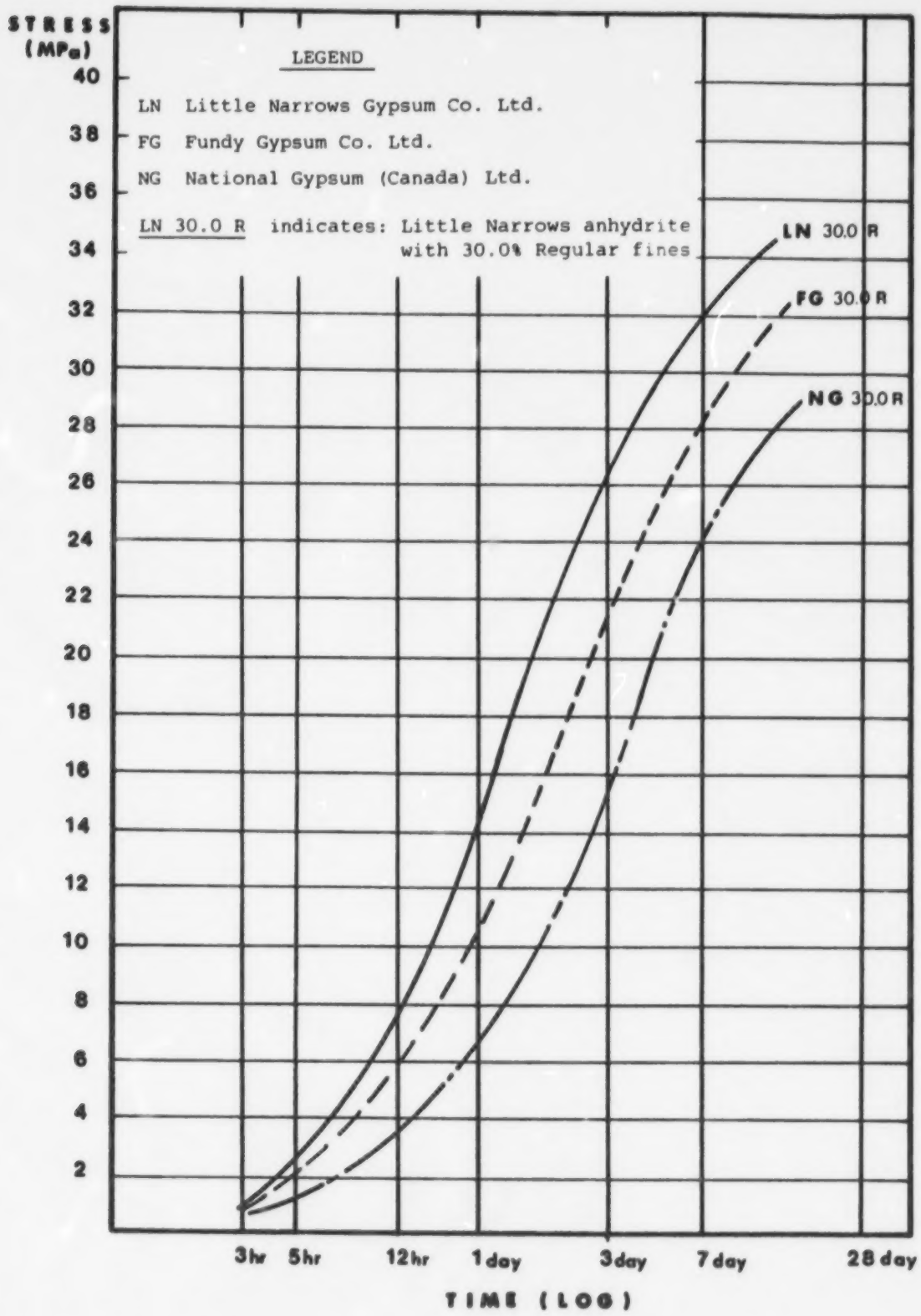


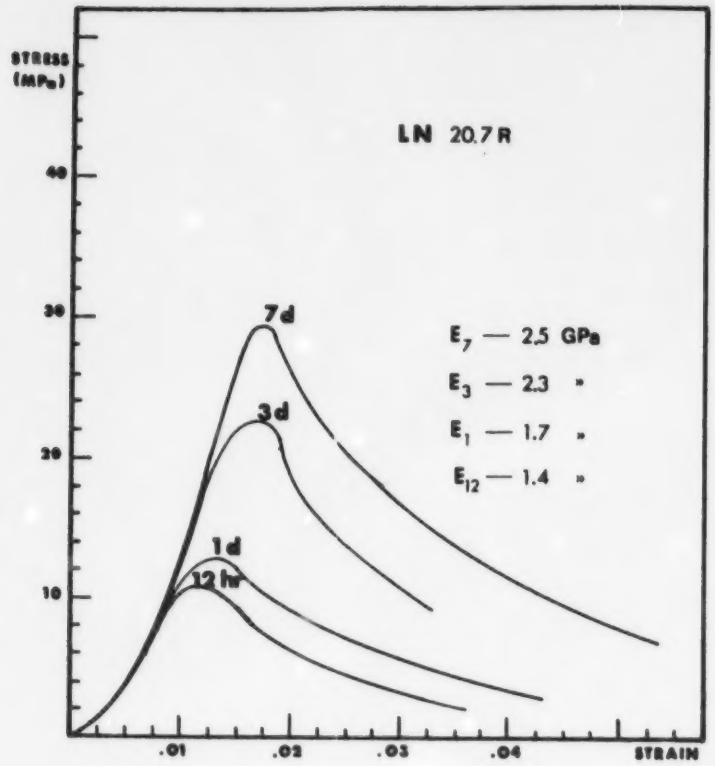
Figure 5.1 Uniaxial Compressive Strength of Regular Mix Anhydrite Materials.

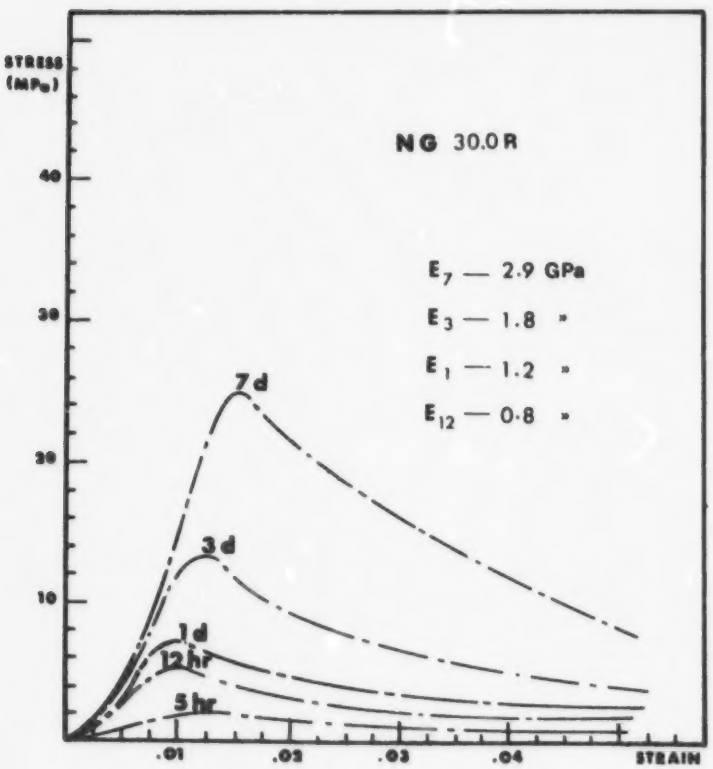
The axial deformation of the anhydrite samples during uniaxial compression tests were recorded using a strain gage based linear displacement transducer (LDT) located between the platens of the compression machine. A record of the stress-strain behavior of four Nova Scotia anhydrite products is presented in Figure 5.2. It is noted that the anhydrite acts plasticly for a very short period after casting. The 12 hour curve for each material displays an elastic behavior with a distinct brittle failure at the ultimate strength. Each material demonstrates increased stiffness with increased set time. The slope of the stress-strain curves appears to be similar for the different materials at each of the tested set-times. There is an increase in stiffness for the Little Narrows material with 30% fines when compared with the same material with only 20.7% fines. The elastic modulus at 50% uniaxial strength for each material is indicated in Figure 5.2.

Due to the lack of high early strength, experimental work was initiated in this contract to improve this characteristic of Nova Scotia anhydrite mixes. The two techniques tested to achieve this improvement were as follows:

- the use of fine grinding the -75 micron fraction of the anhydrite material,
- the addition of fly ash to the anhydrite mix.

The results from this work are presented in the next two sections of this report.


STRESS (MPa)
LN 20.7 R
40
30
20
10
7d
3d
1d
12 hr
E_7 — 2.5 GPa
E_3 — 2.3 »
E_1 — 1.7 »
E_{12} — 1.4 »
.01
.02
.03
.04
STRAIN


STRESS (MPa)
NG 30.0 R
40
30
20
10
7d
3d
1d
12 hr
5 hr
E_7 — 2.9 GPa
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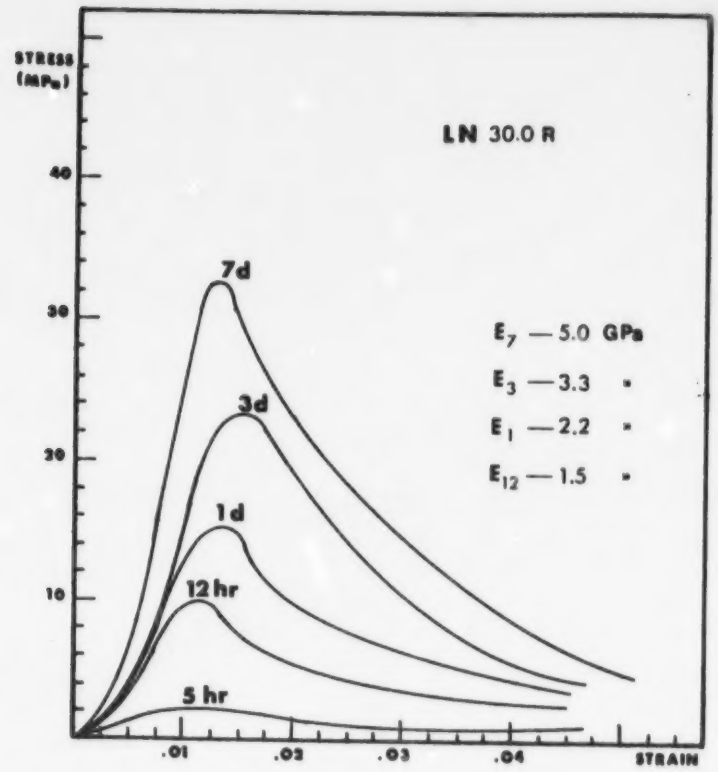
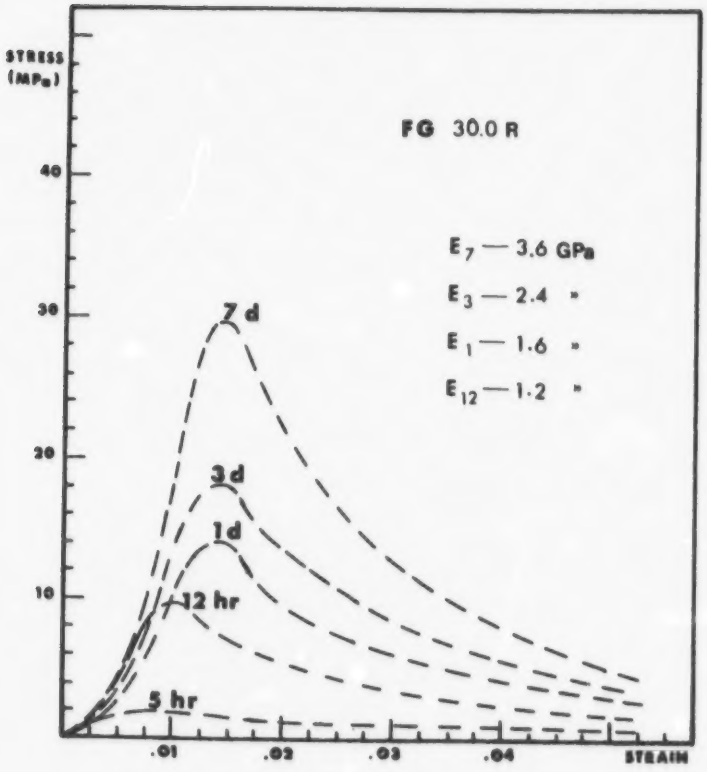




LEGEND

LN Little Narrows Gypsum Co. Ltd.

NG National Gypsum (Canada) Ltd.

FG Fyndy Gypsum Co. Ltd.

LN 20.7 R indicates: Little Narrows anhydrit
with 20.7% Regular grin

Figure 5.2 Stress-Strain Curves for Nova Scotia Anhydrite material with Regular Grind Fines.

5.2 Evaluation of Fine Grinding the -75 micron Size Fraction and Its Effects on the Early Strength Development of Anhydrite

The technology of high-early strength development in portland cement products is well established. One of the techniques used to accomplish high early strength is to fine grind the portland cement to increase the surface area per volume of material to provide increased sites for hydration reactions to occur. Accelerators and other additives are also used in the manufacture of these high early strength cement products; however, the finely ground cement is a major contributor to the development of high-early strength in these products (Langley W. S.).

It was the opinion of the investigators that fine grinding the -75 micron size fraction of the crushed anhydrite product would accelerate the early strength development of the anhydrite construction material. Fine grinding of the -75 micron anhydrite was accomplished using a laboratory rod mill. Initial tests were conducted by fine grinding products from Little Narrows and Fundy Gypsum for 30 minutes. The size reduction accomplished by the rod mill grinding is given in Table 5.1 and illustrated in Figure 5.3. This information demonstrates a shift of the size distribution curve to the right of Figure 5.3, which indicates an increase in fineness of the anhydrite particles. Another, more direct indicator of the particle fineness is the specific surface area measurement (m^2/cc) provided by the Malvern Instruments,

Laser Size Analyser used for this work. The specific surface area values for the anhydrite products are included in Table 5.1. It is observed that the specific surface area of both the Little Narrows and Fundy Gypsum anhydrites were increased approximately 250% by the 30 minute fine grinding action in the laboratory rod mill.

Table 5.1

Size Distribution of -75 micron Anhydrite Before and After 30 minute Fine Grind in a Laboratory Rod Mill

Size (micron)	Little Narrows (Cumulative %)		Fundy Gypsum (Cumulative %)	
	No Fine Grind	Fine Grind (30 min)	Regular	Fine Grind (30 min)
180	100.0	100.0	100.0	100.0
150	99.8	100.0	100.0	100.0
125	99.4	100.0	100.0	100.0
90	98.8	100.0	98.1	100.0
75	97.6	100.0	95.3	100.0
63	94.5	100.0	90.9	99.9
45	82.1	99.4	76.7	98.8
32	64.2	96.8	59.6	94.5
27.6	46.9	84.8	44.0	80.1
16.0	29.6	66.2	28.1	64.5
11.3	18.1	46.1	17.5	44.8
8.0	11.6	31.7	11.2	30.1
5.7	6.1	17.7	5.9	16.8
4.0	3.5	9.4	3.1	8.5
2.8	2.4	6.0	1.8	5.8
2.0	1.5	3.5	1.0	3.0
1.7	1.1	2.4	0.7	1.9
Surface Specific Area (m^2/cc)	0.10	0.25	0.09	0.22
(% increase)	Base (100%)	(250%)	Base (100%)	(244%)

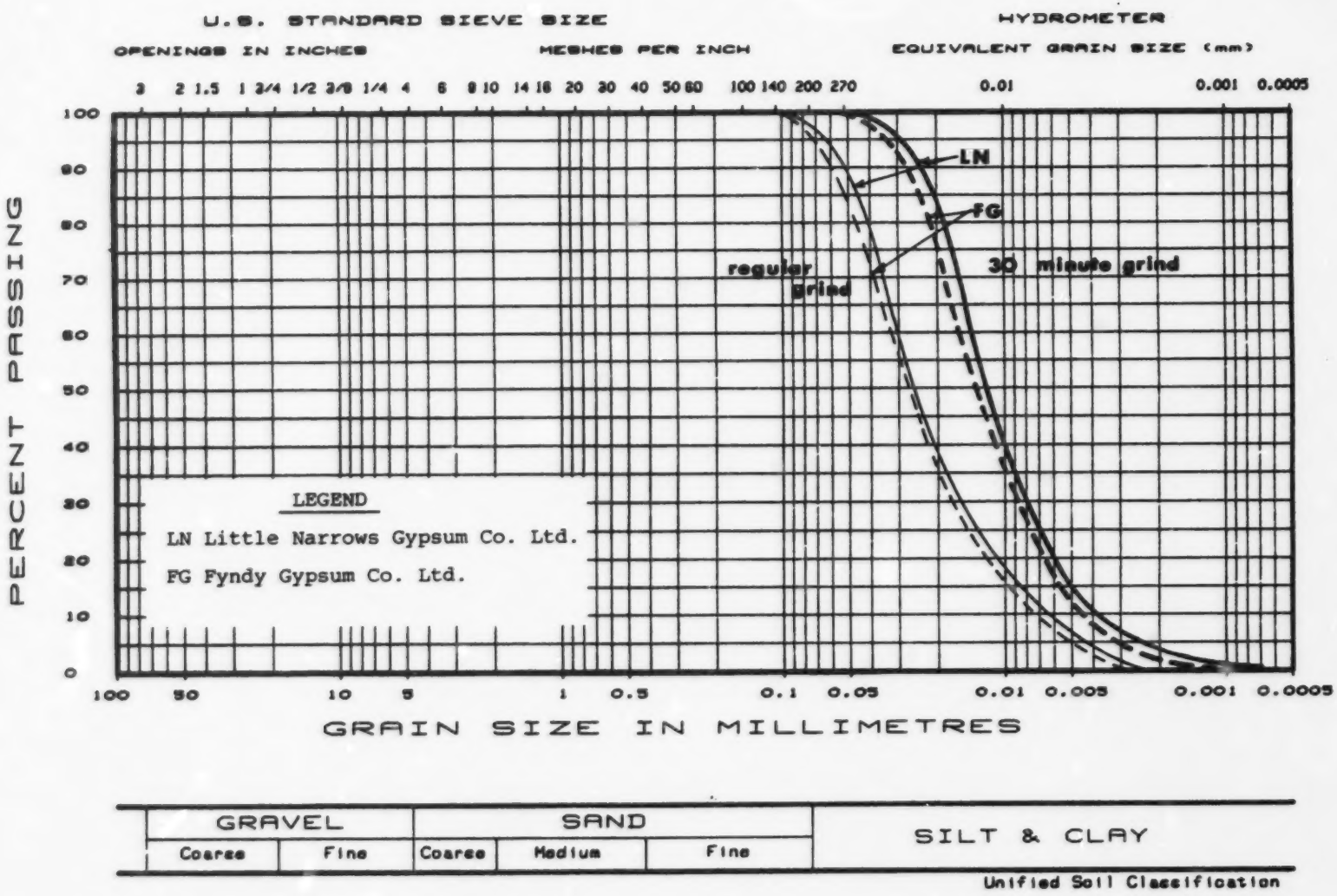


Figure 5.3 Size Distribution of the -75 micron fraction Anhydrite Before and After 30 minute Fine Grind in a Laboratory Rod Mill.

The -75 micron, 30 minute fine grind product was used to prepare anhydrite construction material test specimens to evaluate the effect fine grinding had on mechanical strength development. This work was restricted to anhydrite samples from Little Narrows and Fundy Gypsum with 30% fines (-75 micron, 30 minute fine grind). Uniaxial compression tests were conducted on these specimens and the results are shown in Figure 5.4. In Figure 5.4, graphs of strength development are also shown for the regular -75 micron fines mixes for Little Narrows and Fundy Gypsum. A comparison of the graphs for specimens with 30 minute fine grind versus regular fines shows there is an increase in the early strength of the anhydrite specimens with 30 minute fine grind -75 micron material. This increase in strength development is presented in Table 5.2 for 3 hours and 5 hours.

Table 5.2
Increase in Uniaxial Compressive Strength
For 30 minute grind -75 micron Fines vs
Regular Fines Anhydrite Material

	LITTLE NARROWS			FUNDY GYPSUM		
Details	Specific Surface Area of -75 micron (m^2/cc)	Compressive Strength (MPa) 3 Hr	5 HR	Specific Surface Area of -75 micron (m^2/cc)	Compressive Strength (MPa) 3 HR	5 HR
Regular Fines	0.10	0.8	1.9	0.09	0.6	2.1
30 minute fine grind, -75 micron	0.25	3.1	5.5	0.22	1.9	5.4
% increase in compressive strength	250%	280%	190%	244%	190%	160%

In Figure 5.4 it is also noted there is a general shift to the left for the strength development curves of the fine grind -75 micron products versus the regular fines products. This fact indicates that for a given cure time the fine grind -75 micron product developed a higher strength than the regular fines anhydrite product.

Based on the positive results obtained from the 30 minute fine grind tests which indicated an increased early strength with fine grind, tests were conducted to further define the relationship between the fineness of grind of the -75 micron size fraction and the increased high early strength. Samples of the -75 micron material were prepared at 15 minute and 59 minute grind times in the laboratory rod mill. Test specimens were prepared and tested using these two additional fines materials to supplement the data previously determined for 30 minute fine grind. These additional fine grind tests were restricted to Little Narrows anhydrite with specimens containing 30% fines material. The size distribution of the -75 micron fraction for the 15, 30 and 59 minute grinds are presented in Table 5.3 and Figure 5.5. Results of the uniaxial compressive strength tests conducted on these specimens are presented in Figure 5.6.

These tests results in Figure 5.6 demonstrate there is an increase in early strength with increased fineness of grind. The late strengths decreased with increased fineness of grind;

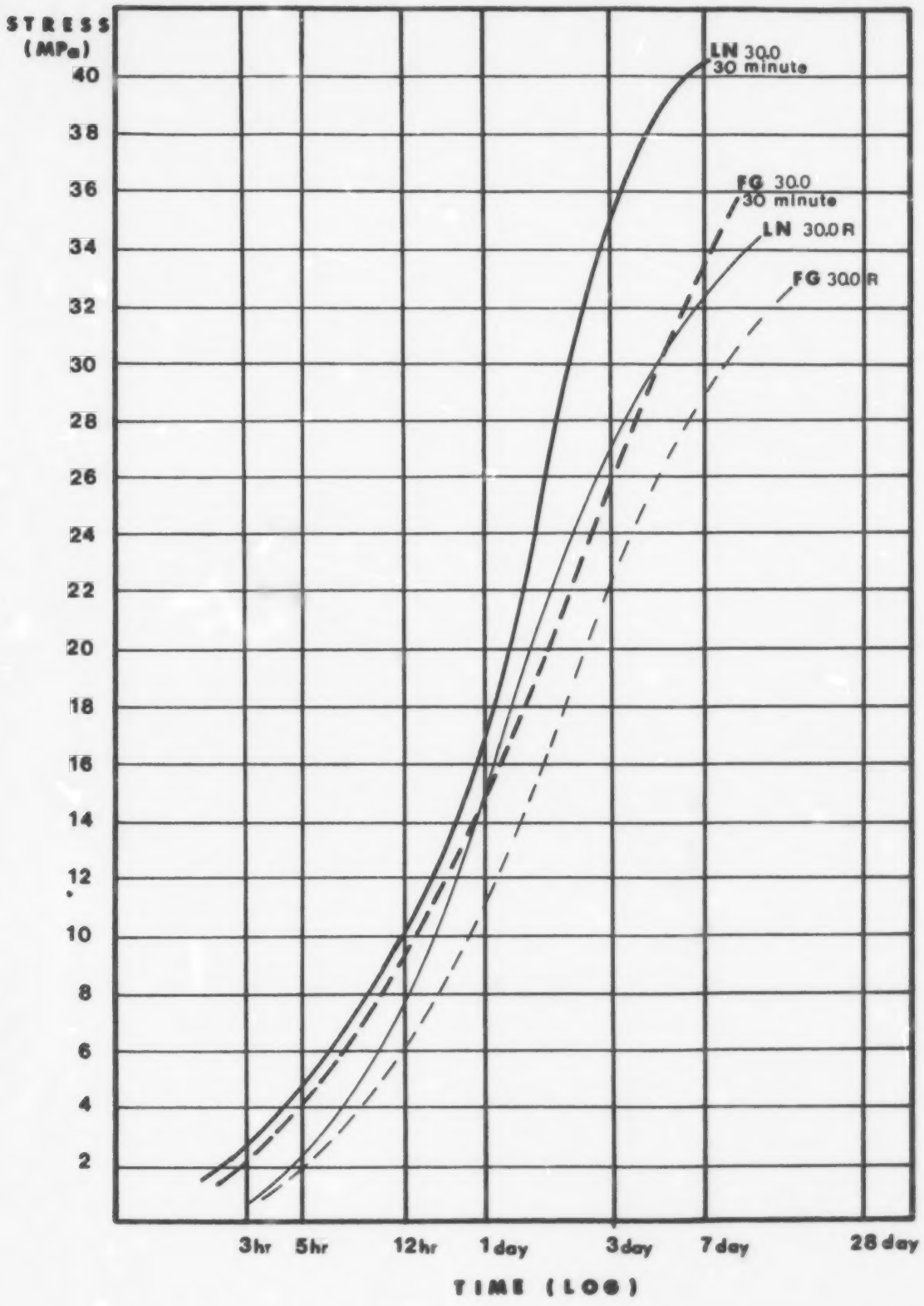


Figure 5.4 Uniaxial Compressive Strength of Anhydrite Materials with 30 minute Fine Grind vs Regular Grind.

however all fine grind specimens demonstrated late strength values which were greater than the late strength of the regular fines product.

TABLE 5.3
SIZE DISTRIBUTION OF -75 MICRON LITTLE NARROWS ANHYDRITE BEFORE FINE GRINDING AND AFTER 15,30 AND 59 MINUTE FINE GRIND IN A LABORATORY ROD MILL
CUMULATIVE %

Size	No Grind	15 Min	30 min	59 min
180.0	100.0	100.0	-	-
150.0	99.8	100.0	-	-
125.0	99.4	100.0	-	-
90.0	98.8	100.0	100.0	-
75.0	97.6	99.6	100.0	-
63.0	94.5	99.1	100.0	100.0
45.0	82.1	96.7	99.4	99.8
31.0	64.2	84.1	96.8	98.8
22.6	46.9	66.0	84.8	91.3
16.0	29.6	45.6	66.2	76.0
11.3	18.1	28.6	46.1	57.0
8.0	11.6	19.1	31.7	43.6
5.7	6.1	10.2	17.7	26.5
4.0	3.5	5.3	9.4	14.7
2.8	2.4	3.7	6.0	10.2
2.0	1.5	2.4	3.5	6.5
1.7	1.1	1.7	2.4	4.6
Specific Surface Area (m^2/cc)	0.10	0.16	0.25	0.29
(% increase)	Base (100%)	160%	250%	290%

The stress-strain behavior of Little Narrows anhydrite product containing 30% -75 micron fines which was fine ground for 59 minutes is provided in Figure 5.7. The stress-strain curves for regular grind Little Narrows anhydrite, 30% fines (no fine grinding) is provided in Figure 5.7 for comparison purposes. The

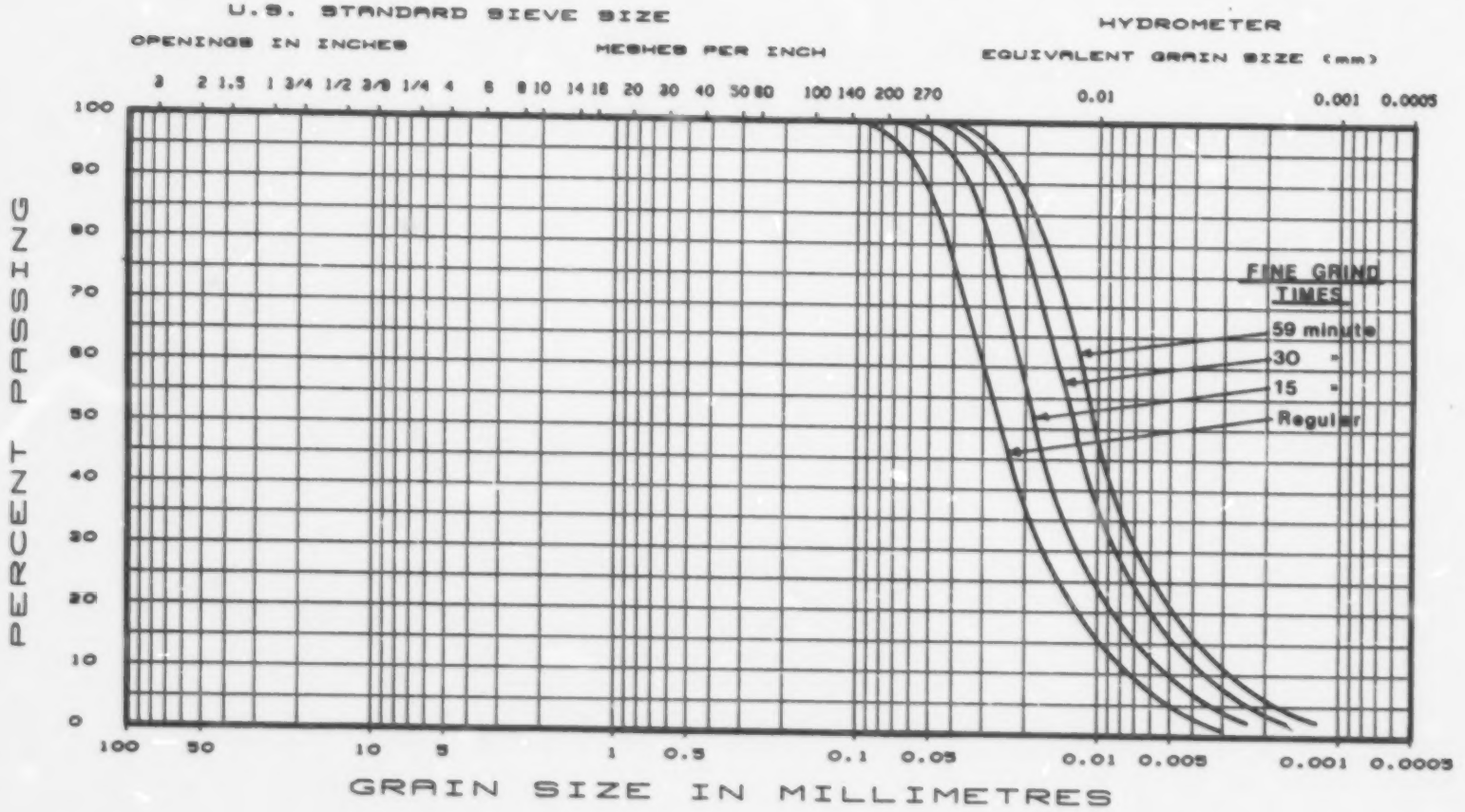


Figure 5.5 Size Distribution of -75 micron Anhydrite Before Fine Grind and After 15, 30, 59 Minute Fine Grind in a Laboratory Rod Mill.

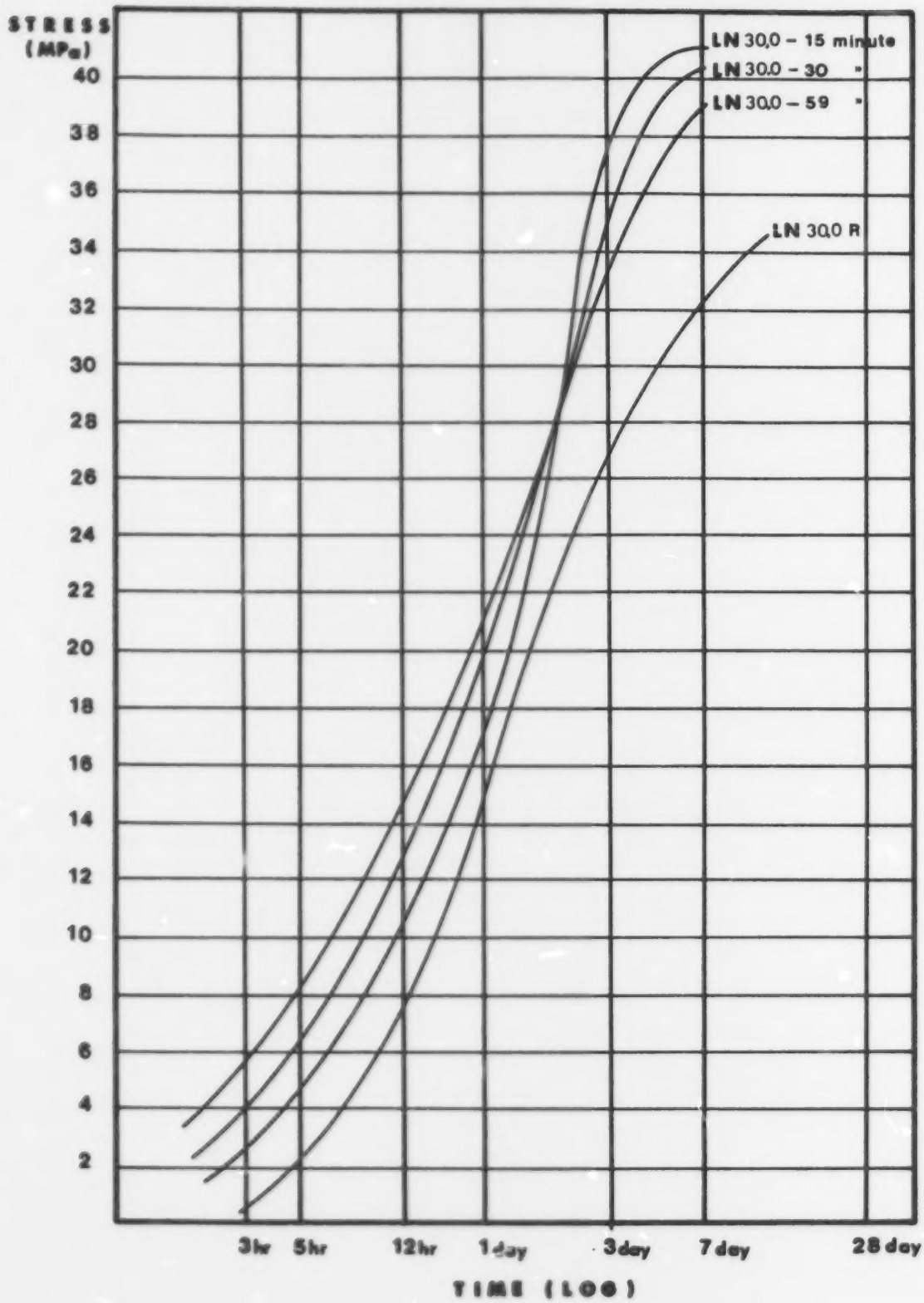
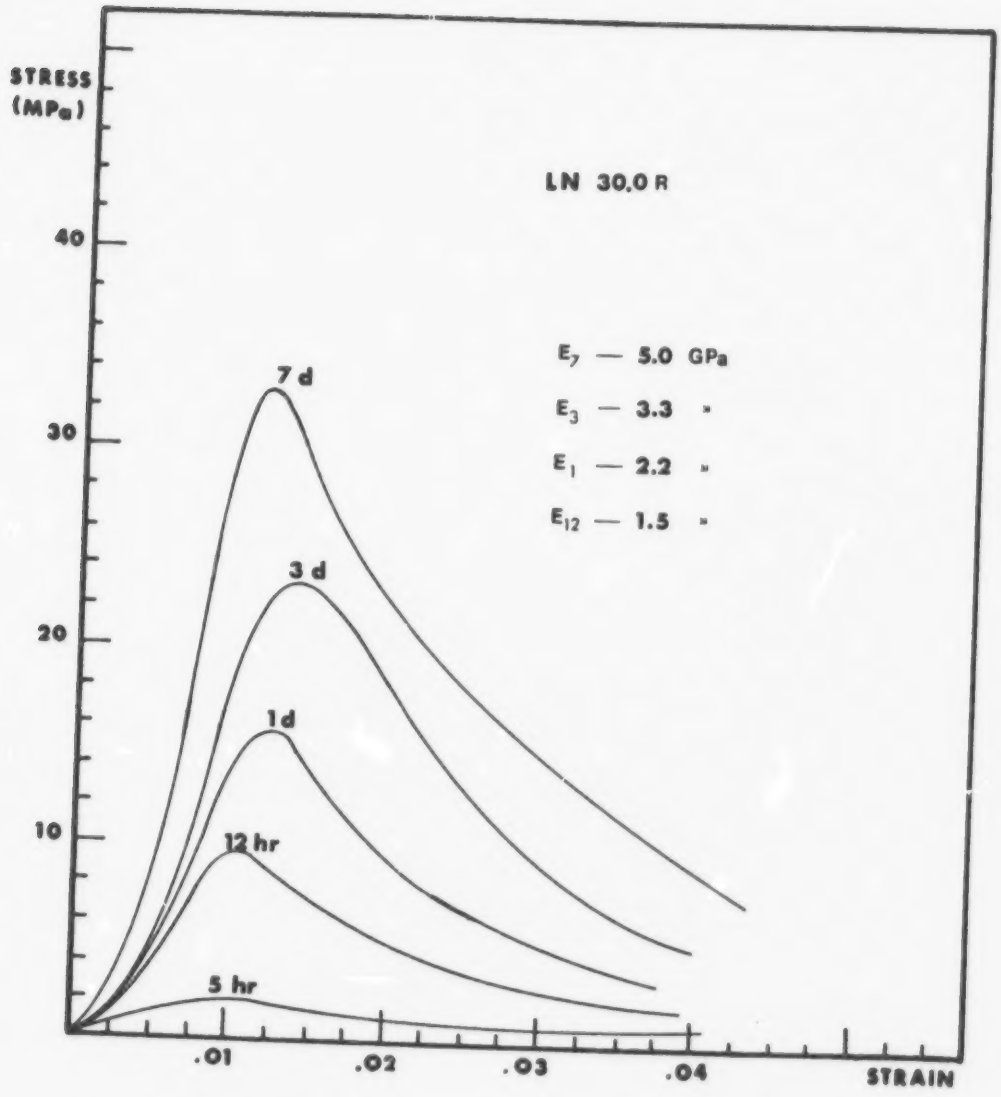


Figure 5.6 Uniaxial Compressive Strength of Little Narrows Anhydrite with 30% Fines and 0, 15, 30 and 59 Minute Fine Grind in a Laboratory Rod Mill.


STRESS
(MPa)
40
30
20
10
LN 30.0 R
E_7 — 5.0 GPa
E_3 — 3.3 "
E_1 — 2.2 "
E_{12} — 1.5 "
7 d
3 d
1 d
12 hr
5 hr
.01
.02
.03
.04
STRAIN

LEGEND

LN 30.0 R indicates: Little Narrows anhydrite with 30.0 % Regular grind fines

LN 30.0 - 59 minute indicates: Little Narrows anhydrite with 30.0% fines that had fine grinding in a laboratory rod mill for 59 minutes

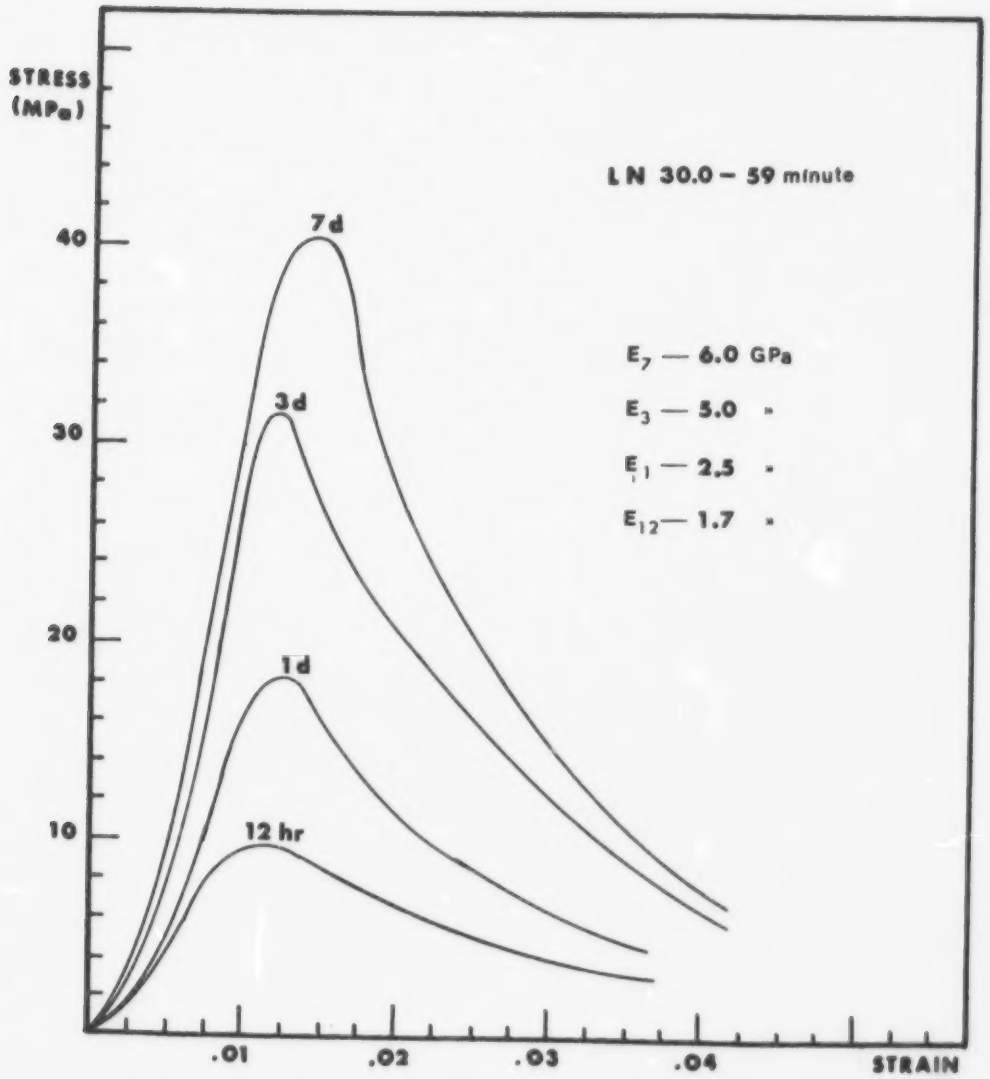


Figure 5.7 Stress-Strain Curves for Little Narrows Anhydrite, 30% fines With and Without Fine Grind on the -75 micron Size Fraction.

slope of the elastic portion of the curves (elastic modulus) for the finely ground -75 micron fines product and the regular product is unchanged despite the increased uniaxial compressive strength for the fine grind product. The fine grind product demonstrates an increased brittle failure responses to the uniaxial compression test. The stress-strain curves for set-times of less than one day were significantly affected by the fine grind. The stress-strain curves for specimens with fine grind and 5 hour set-time show a greatly increased elastic response to the compression tests compared with the plastic behavior of the regular mix 5 hour set-time. Consequently it is concluded that fine grinding the -75 micron size fraction increased the early strength and produced an earlier elastic response of the set anhydrite material.

5.3 Preliminary Evaluation of the Mechanical Properties of Anhydrite Material with the Addition of Fly Ash

The addition of fly ash to natural anhydrite is practiced in Europe to provide a cheap replacement for natural anhydrite in coal mine pack construction work. In addition to reducing the cost of anhydrite packs, the addition of fly ash also modifies the elastic properties of the anhydrite pack material. A 10% to 20% addition by weight is used in European practices (Blom k and Rohrs H, 1985).

Based on this information, it was decided to investigate the potential to use fly ash in Nova Scotia anhydrite to increase the high-early strength required for pack construction materials in lieu of fine grinding the -75 micron size fraction of the anhydrite material.

Fly ash is available in large quantities from the Nova Scotia Power Corporation (NSPC) coal fired electric power generating plant at Lingan, Nova Scotia. The detailed analysis of the Lingan fly ash is outlined in Table 5.4.

Table 5.4
Chemical and Physical Properties of Lingan Power Station (NSPC)
Low Calcium Type F Fly Ash (Langley W. S.)

Chemical Composition	Percent by weight
SiO_2	45.2
Al_2O_3	20.7
Fe_2O_3	24.8
CaO	1.63
MgO	0.97
TiO_2	1.05
SO_3	0.65
K_2O	2.40
Na_2O	0.59
Loss on Ignition (%)	2.66
Blaine Fineness (m^2/kg)	478
Percent Finer Than 45 micron	84
Relative Density	2.54

This source of fly ash is in close proximity (3 km) to the CBDC coal mines (Lingan and Phalen Collieries) where anhydrite packs are proposed for use.

Preliminary tests were conducted on the addition of 10% fly ash (by weight) to Little Narrows anhydrite material. The fly ash was dry-blended with two anhydrite material mixes as follows:

. Little Narrows, 20.7% regular fines + 10% fly ash
. Little Narrows, 30%, 30 minute grind fines + 10% fly ash.

Uniaxial compression tests were performed on test specimens of these mixes and the results are presented in Figure 5.8. Comparison graphs for the same anhydrite material mixes without fly ash are also presented in Figure 5.8.

It is concluded from this work that the 10% fly ash addition produced an increased early strength for both anhydrite mixes. The increased strength of the 20.7% regular fines mix was from 2.08 to 3.12 MPa (50% increase) for 5 hour cure time while the 30%, 30 minute fine grind mix increased in early strength at 5 hours from 6.38 to 10.52 MPa (65% increase). The effect of the fly ash addition on increased late strength was not as significant as for the early strengths.

The stress-strain relationship for the anhydrite with 10% fly ash addition are presented in Figure 5.9 for 20.7% regular grind and in Figure 5.10 for 30%, 30 minute grind Little Narrows anhydrite. It is observed that the addition of fly ash generated a "stiffening" of the 20.7% fines Little Narrows regular grind

anhydrite product, while it had little effect on the stiffness of the 30% fines, 30 minute grind Little Narrows anhydrite mix. The fly ash caused a very rapid development of early strength (1.6 MPa in 1 hr. and 4.6 MPa in 2 hr.) in the 30%, 30 minute grind product while it created only a limited increase in early strength of the 20.7% regular fines product.

These test results indicate the potential to use fly ash as an additive in anhydrite mixes to accelerate the development of early strength for mine pack construction work. The difference in strength development with 15% fly ash addition in the 30%-30 minute grind and 20.7% regular grind indicates the importance of the finely ground anhydrite in combination with the presence of fly ash. It is commented that more extended testing on anhydrite and fineness of grind of the anhydrite should be performed prior to adopting the addition of fly ash for industrial application in Nova Scotia.

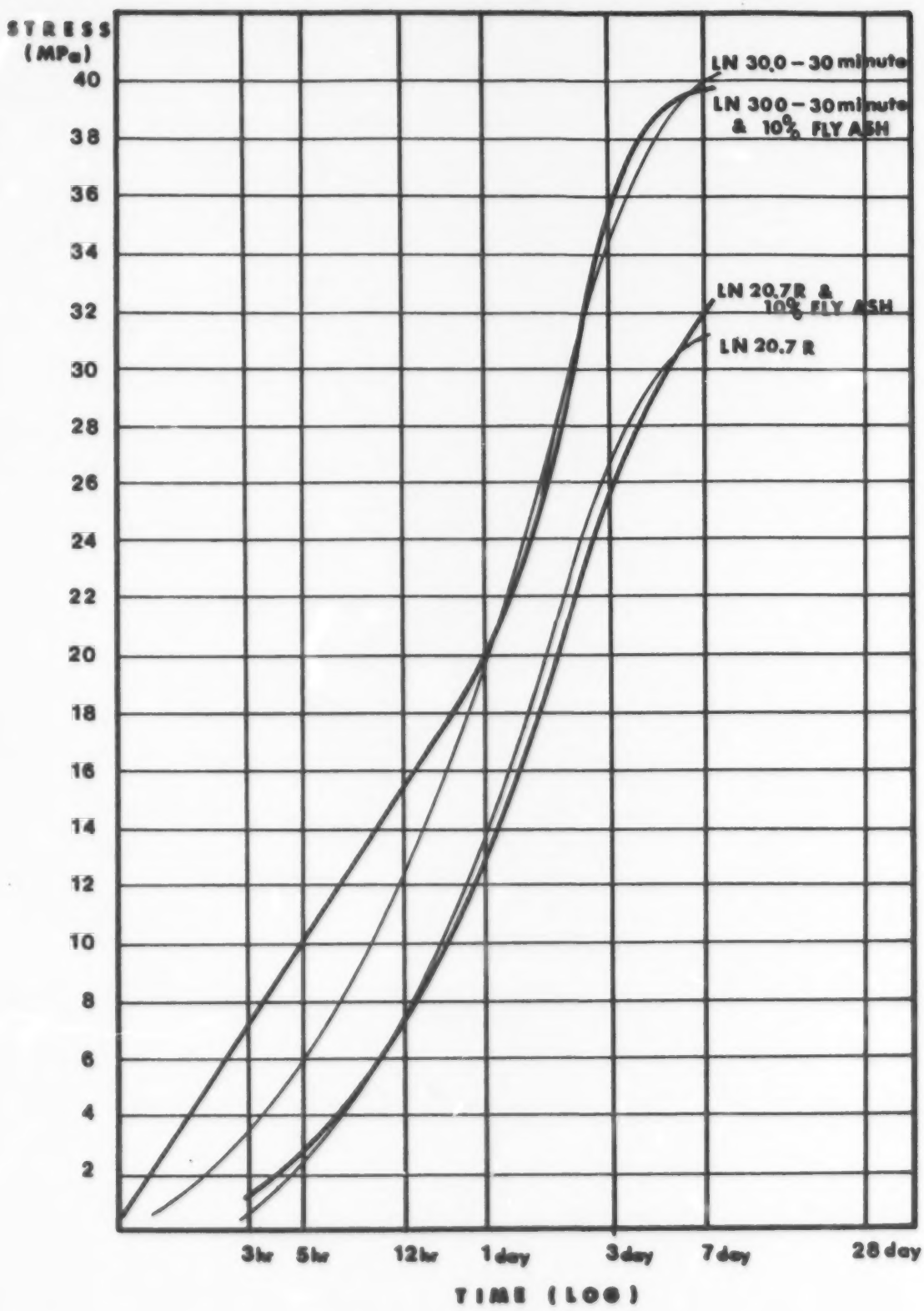
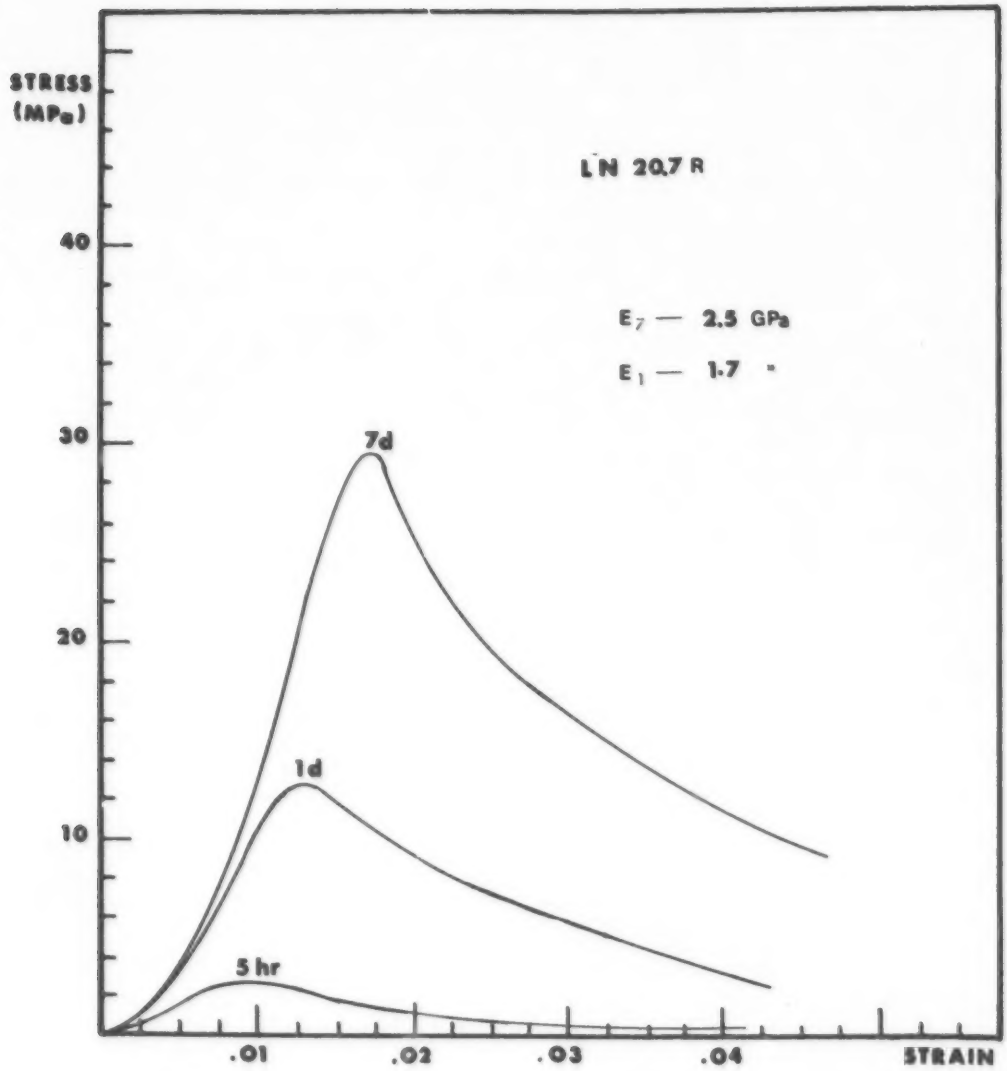


Figure 5.8 Uniaxial Compressive Strength of Little Narrows Anhydrite with 10% Fly Ash Addition.


STRESS
(MPa)
40
30
20
10
LN 20.7 R
E_7 — 2.5 GPa
E_1 — 1.7 "
7d
1d
5 hr
.01
.02
.03
.04
STRAIN

LEGEND

LN 20.7 R indicates: Little Narrows anhydrite with 20.7% Regular grind fines

LN 20.7 R & 10% Fly Ash indicates: Little Narrows anhydrite with 20.7% Regular grind fines and the addition Type F Lingan Power Station fly ash in an amount equal to 10.0% by weight of the anhydrite

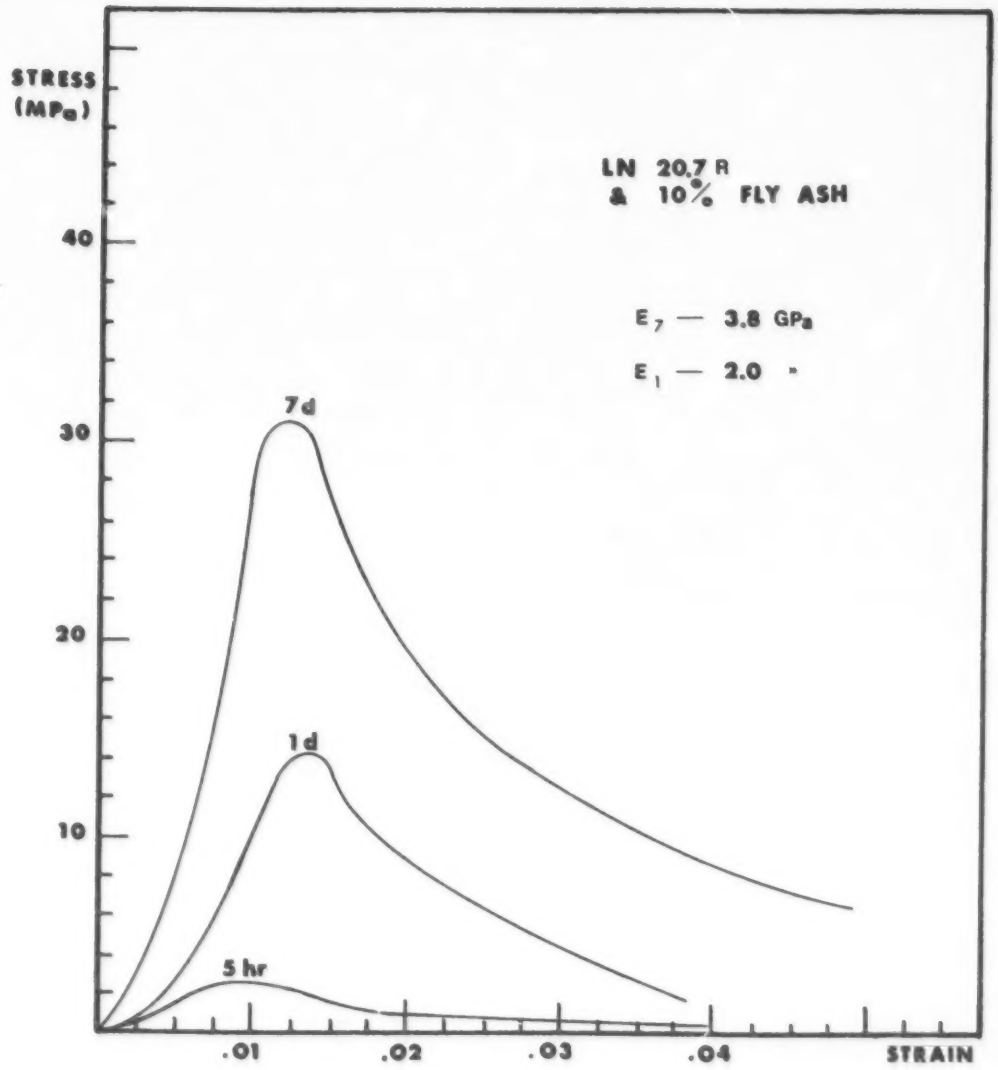


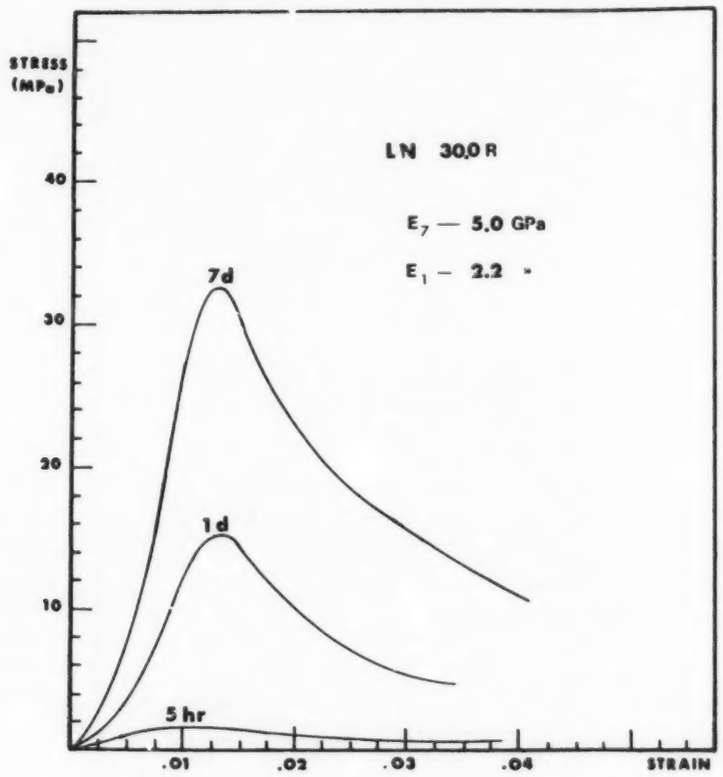
Figure 5.9 Stress-Strain Curves for Little Narrows Anhydrite with 20.7% Regular Fines and 10% Fly Ash Addition.

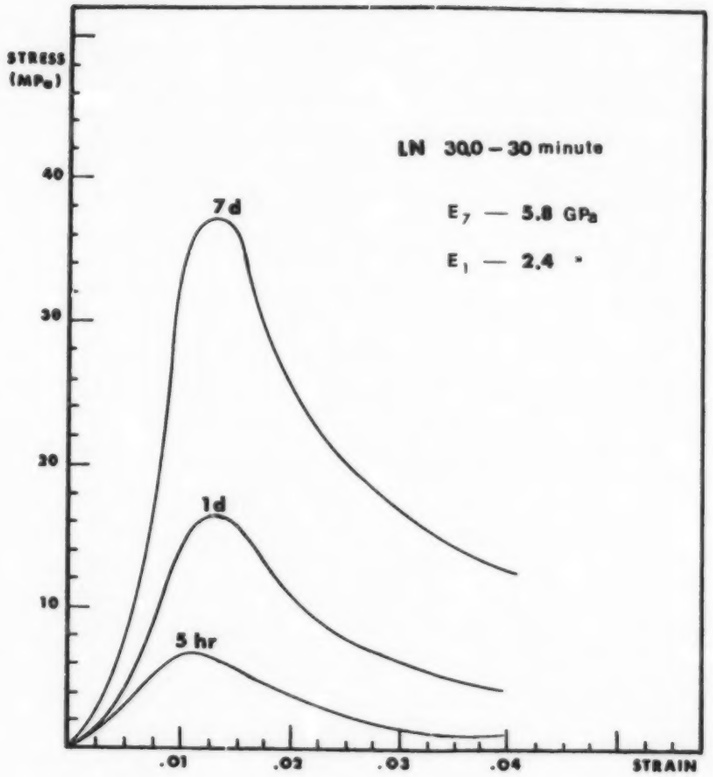
LEGEND

LN 30.0 R indicates: Little Narrows anhydrite with 30.0% Regular grind fines

LN 30.0 - 30 minute indicates: Little Narrows anhydrite with 30.0% fines that had fine grinding in a laboratory rod mill for 30 minutes

LN 30.0 - 30 minute & 10% Fly Ash indicates: Little Narrows anhydrite with 30.0% fines that had fine grinding in a laboratory rod mill for 30 minutes and the addition of Type F Lingan Power Station fly ash in an amount equal to 10% by weight of the anhydrite





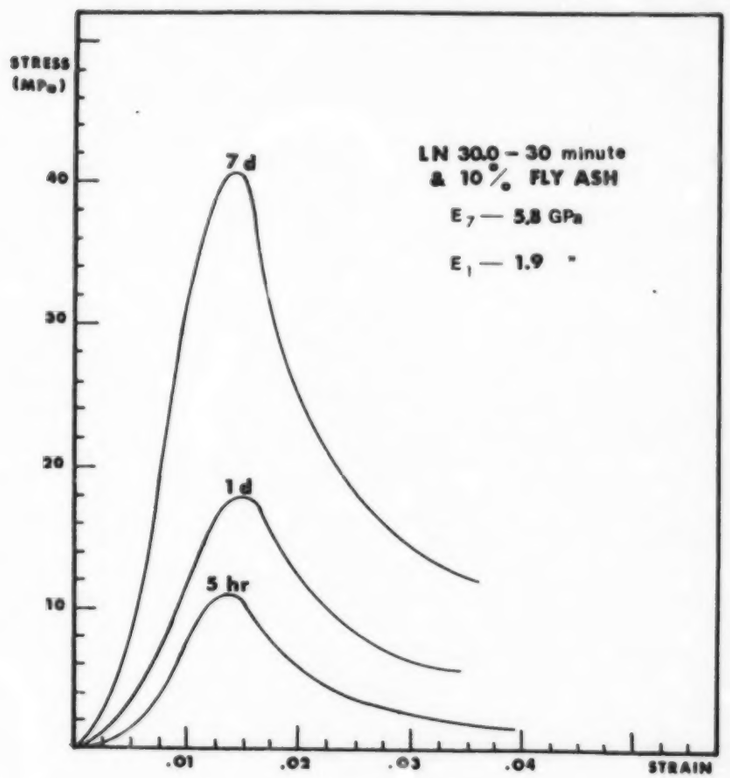


Figure 5.10 Stress-Strain Curves for Little Narrows Anhydrite with 30%, 30 Minute Fines Grind and 10% Fly Ash Addition.

6. CEMENTITIOUS PROPERTIES OF NOVA SCOTIA ANHYDRITES - A DETAILED EVALUATION

The investigation that was detailed in previous sections of this report indicate the potential to use Nova Scotia anhydrite as a cementitous construction material in coal mines. A wide range of mechanical strengths were defined using variations in fineness of grind and the addition of fly ash. It was also reported that not all Nova Scotia anhydrites are suitable for this application. Anhydrites from Little Narrows, Fundy Gypsum and National Gypsum are all suitable (listed in order of decreasing strength) while the Georgia Pacific anhydrite was reported to be unsuitable. This section of the report will propose explanations for these observations.

Extended tests were also conducted at the end of the product test work to define the effect of the cure environment on the set characteristics of the anhydrite.

6.1 Cure Environment

Throughout the detailed test program, anhydrite curing was done at room temperature and humidity. In Section 4.3 it was reported that the humidity of the cure environment had a significant effect on the strength development of the anhydrite material. Extended testing was done on the Little Narrows

product to further define this relationship for a Nova Scotia anhydrite product that was designated as appropriate for pack construction work. A mix of anhydrite was prepared as follows:

Little Narrows - 30% fines, 30 minute fine grind
- 8.5 % water
- 2 % accelerator

mixed and cast into 40 x 40 x 160 mm molds. These specimens were cured in three separate environments which had the following relative humidities:

Room Atmosphere - 30%

Chamber - 75%

Bagged (sealed) - 100%

The ambient temperature for each environment was 75°F. The results of uniaxial strength tests during the cure period of 7 days is shown in Figure 6.1. It is observed from this information there are three (3) individual strength curves for the same anhydrite mix resulting from a variation in relative humidity of the cure environment. The relationship that was established indicates an increased strength with decreased humidity. Figure 6.2 describes the elastic properties of the anhydrites cured in the different environments. The stress-strain relationships in Figure 6.2 illustrate that for a 3-day cure period, the drier the atmosphere the "stiffer" the anhydrite material.

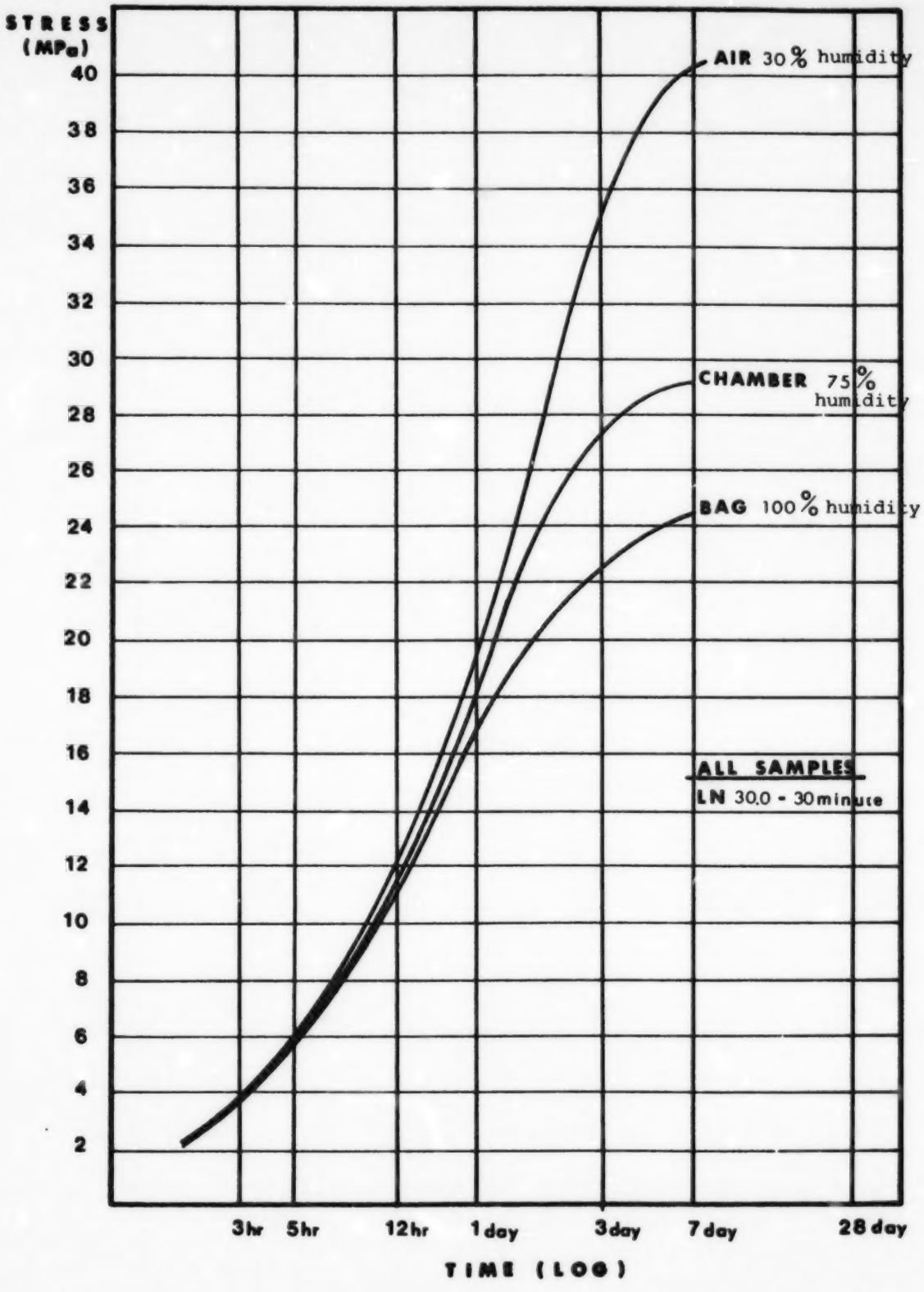


Figure 6.1 Effect of % Humidity on the Uniaxial Compressive Strength of Little Narrows Anhydrite (30% Fines with 30 Minute Fine Grind).

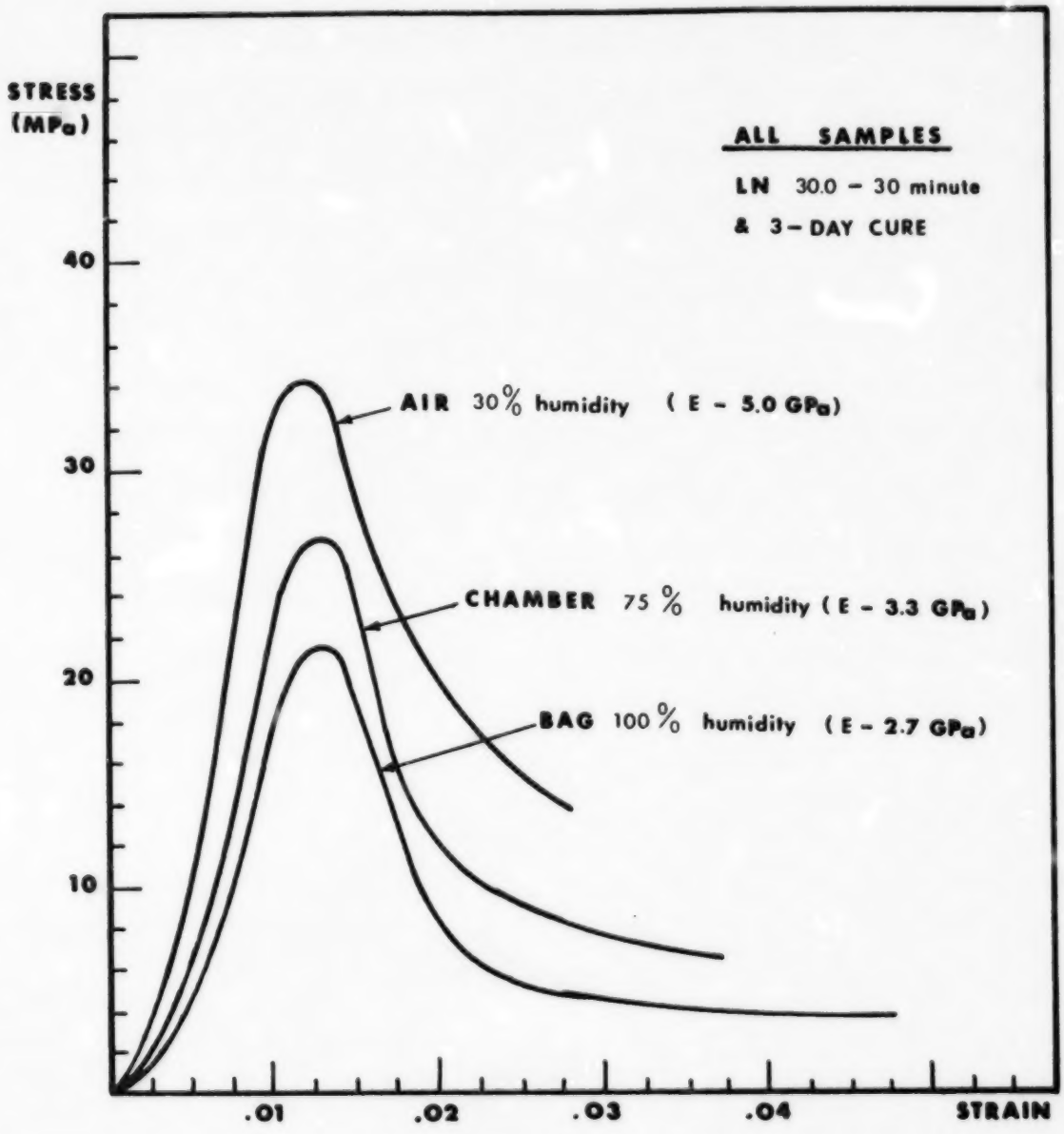


Figure 6.2 Effect of Humidity on the Stress - Strain Curves of Little Narrows Anhydrite (30% fines with 30 minute fine grind) at a 3- Day Cure Period

6.2 Composition of Cured Anhydrite Specimens

Whole-rock analyses were performed on 'fully' cured (+28 day) anhydrite construction materials to determine the change in composition of the anhydrite materials resulting from the hydration reaction. This analysis is presented in Table 6.1. Table 3.1 is reproduced along with Table 6.1 to facilitate easy comparison between the original and hydrated anhydrite materials.

The point of major interest in these analyses is the portion of anhydrite which is converted to gypsum by the hydration reaction. Since it is this reaction that is reported by the literature to be responsible for the strength development of anhydrite pack materials it would be natural to think the stronger materials would be associated with increased conversion of anhydrite to gypsum. A comparison between the amount of anhydrite and gypsum present in the natural rock and the cured anhydrite construction material is given in Table 6.2. This information indicates that the anhydrite to gypsum conversion demonstrated the following conditions:

- the conversion of anhydrite to gypsum is a balanced (1:1) reaction with minor variation,
- approximately 1/4 (22.44% to 27.52%) of the available anhydrite was converted to gypsum,
- there appears to be no variation in the production of gypsum in the test specimens despite such changes as source, % fines, % water, % accelerators and fly ash additive.

TABLE 6.1

COMPOSITION OF CURED (+28 DAY) ANHYDRITE PACK CONSTRUCTION MATERIALS (WHOLE-ROCK ANALYSIS)

ANALYSIS	GEORGIA PACIFIC	PRODUCT "K"	FUNDY GYPSUM	LITTLE NARROWS	LITTLE NARROWS	LITTLE NARROWS	LITTLE NARROWS	LITTLE NARROWS
%FINES	20.7	20.7	24.7	20.7	24.7	30.0	30.0(30)	30.0(30)
%water	9.0	8.5	9.0	8.0	9.0	8.5	9.5	9.5
%additives	-	N/A	-	-	-	-	-	10% Flyash
%accelerator	1.0	N/A	1.0	1.0	1.0	1.5	1.5	1.5
Moisture	0.11	0.53	0.21	0.31	0.26	0.40	0.43	0.17
Combined Water (LOI)	5.21	5.05	6.64	5.53	6.02	5.44	5.43	5.47
SO	53.84	50.17	54.05	53.70	53.78	53.91	54.04	49.40
CaO	37.87	35.85	37.90	37.66	37.70	37.88	37.90	34.67
Fe_2O_3	0.15	0.42	0.25	0.19	0.19	0.48	0.35	2.70
K_2O	0.15	0.32	0.11	0.10	0.17	0.19	0.26	0.39
SiO_2	0.21	2.36	0.27	0.40	0.27	0.30	0.28	3.67
Al_2O_3	0.14	0.71	0.12	0.13	0.13	0.13	0.11	1.66
MgO	0.015	1.35	0.03	0.11	0.08	0.09	0.13	0.16
Gypsum	24.89	24.13	31.73	26.42	28.76	25.99	25.94	26.14
Anhydrite	71.85	66.21	66.80	70.40	68.68	71.10	71.36	63.31
$CaCO_3$	0.32	1.26	0.07	0.07	0.05	0.11	0.08	0.12
NaCl	0.02	0.12	0.023	0.014	0.021	0.017	0.018	0.027

Table 6.2
COMPARISON OF ANHYDRITE TO GYPSUM CONVERSION IN THE ACCELERATED HYDRATION REACTION

DETAILS OF ANHYDRITE MIX					COMPOSITION			
Source	% Fines	% Water	% Accelerator	% Additives	Component	Natural Rock (Table3.1)	Cured Anhydrite Material (Table6.1)	Change in % Composition
Georgia Pacific	20.7	9.0	1.0	-	Anhydrite	96.14	71.85	(24.29)
				-	Gypsum	4.01	24.89	+20.88
Fundy Gypsum	24.7	9.0	1.0	-	Anhydrite	93.02	66.80	(26.22)
					Gypsum	6.26	31.73	+25.47
Little Narrows	20.7	8.0	1.0	-	Anhydrite	96.20	70.40	(25.80)
					Gypsum	2.00	26.42	+24.42
Little Narrows	24.7	9.0	1.0	-	Anhydrite	96.20	68.68	(27.52)
					Gypsum	2.00	28.76	+26.76
Little Narrows	30.0	8.5	1.5	-	Anhydrite	96.20	71.10	(25.10)
					Gypsum	2.00	25.99	+23.99
Little Narrows	30.0 (fine grind)	9.5	1.5	-	Anhydrite	96.20	71.36	(24.84)
					Gypsum	2.00	25.94	+23.94
Little Narrows	30.0 (fine grind)	9.5	1.5	10% Fly Ash	Anhydrite	87.45	63.31	(24.14)
					Gypsum	1.82	26.14	+24.34
Product "K"	20.7	8.5	N/A	N/A	Anhydrite	88.65	66.21	(22.44)
					Gypsum	2.91	24.13	+21.22

It was demonstrated in product testing that the mechanical strength of each materials shown in Table 6.2 varied considerably. Special reference is made to the poor strength development of Georgia Pacific anhydrite compared with much stronger Little Narrows products. In all the cured anhydrite materials shown in Table 6.2, the % gypsum and anhydrite are relatively constant. It is therefore concluded that the conversion of anhydrite to gypsum by itself does not determine the mechanical strength of the cured anhydrite material.

As a result of this conclusion it was decided to conduct an examination on the lithology and petrographic character of the anhydrite rocks and cured anhydrite material.

6.3 Petrographic Evaluation of Anhydrite Rocks and Hydrated Anhydrite Test Specimens

Prepared by: Robert Boehner, Regional Geologist
Nova Scotia Department of Mines and Energy

6.3.1 Introduction

Anhydrite rock sampled from three deposits in Nova Scotia were examined: GP from the Sugar Camp Quarry of Georgia Pacific Corporation Ltd., Cape Breton Island; FG from the Wentworth Quarry of Fundy Gypsum Co. Ltd., Windsor; and LN from the Little Narrows Quarry of Little Narrows Gypsum Co. Ltd., Cape Breton Island. The samples were examined to describe their basic

lithology and general petrographic character. In addition thin sections from test blocks of the anhydrite product were examined.

The thin sections were of fair quality with excess thickness and degradation of portions to an amorphous state due to overheating? - grinding process?.

The three anhydrite rock samples display remarkably diverse and distinctive textures both macroscopically and microscopically. This illustrates a portion of the broad range of anhydrite lithology and texture within the Windsor Group. The extent to which these samples are representative of the deposits cannot be assessed.

Grain size variation between the samples is the most striking characteristic. The GP sample is relatively homogeneous, sugary, coarse to very coarse grained (0.5-1.0 mm, locally up to 2 mm), with well developed fractures and cleavage. The LN sample (although relatively homogeneous) in contrast is fine to very fine (0.04-0.05 mm, locally up to 0.1 mm). FG sample has a bimodal grain size; very fine grained (0.01-0.02 mm) with coarser radial fibrous (acicular) component (0.1-0.4 by 0.02 mm). Grain size, therefore may be considered a dominant control on the behavior (reactivity) of the anhydrite rock after crushing and preparation for the test mixtures.

6.3.2 Anhydrite Rock Samples, General Description

(i) GP-Georgia Pacific

GENERAL Coarse grained, crystalline

Megascopic, Rock Slab

Light grey to white color, obvious granular somewhat crumbly anhydrite with crystals-grains 1 mm, and wispy vague medium grey stringers defining a crude lamination or banding 1-2 mm.

Microscopic, Thin Section (Photomicrograph 1)

Dominantly coarse grained anhydrite, 0.5-1.0 mm crystals, intercrystal boundaries are relatively straight, smooth to moderate curves, contacts are well defined and sharp with rare enfacial triple junctions. Minor dispersed nebulous clots and clusters of brownish, very fine grained, carbonate? crystals (0.005 mm). Some clusters comprise coarser 0.02 mm crystals with intergrown sutured boundaries.

Photomicrograph 1. Anhydrite Rock - Georgia Pacific Corp.

(ii) FG-Fundy Gypsum

GENERAL Very fine grained massive anhydrite (0.01-0.02 mm) with subequal clusters of acicular anhydrite (0.1-0.4 mm by 0.02 mm).

Megascopic, Rock Slab

Light bluish grey, fine grained anhydrite with vague fine nodular texture emphasized by coloration and in part by wispy carbonate stringers.

Microscopic, Thin Section (Photomicrograph 2)

Very fine grained anhydrite, with laths 0.01-0.02 mm without apparent organization (not unusual at this scale). Scattered within and locally dominating are bunches or clusters of acicular radial fibrous anhydrite crystals. Individual crystals are needles 0.1-.4 mm by 0.02 mm and form extended clusters (with radial extinction) up to 1-2 mm long. Some portions of the clusters have gypsum replacement. Overall the matrix and clusters acicular are subequal components.

Photomicrograph 2. Anhydrite Rock - Fundy Gypsum Co. Ltd.

(iii) LN-Little Narrows

GENERAL Fine to very fine grained (0.04-0.05 mm) anhydrite with rare acicular gypsum and minor carbonate.

Megascopic, Rock Slab

Brown grey anhydrite with minor wispy brown carbonate stringers and clots. Trace of 0.2 mm borate? minerals. The distinctive circular features observed in thin section are not apparent.

Microscopic, Thin Section (Photomicrograph 3)

The anhydrite throughout is fine to very fine grained (0.04-0.05 mm, rare up to 0.1 mm). Locally there are bunches of acicular radial fibrous gypsum crystals up to 2 mm. The thin section macroscopically displays a very distinctive texture with 0.5-5 mm diameter circular (spherical ?) structures. In thin section, these are defined by a thin envelope of brownish, fine

Photomicrograph 3. Anhydrite Rock- Little Narrows Gypsum Co. Ltd.

grained carbonate? rich anhydrite within a dominantly very fine (0.04-0.05 mm) anhydrite matrix. There is an appearance of replacement relationship with carbonate infilled and in part replaced by anhydrite. There is a conspicuous porosity, 2-5% estimate, that appears to be associated with the cores of the circular features, this may be due to plucking and or perhaps to the dissolution of salt.

6.3.3 Anhydrite Test Blocks

Thin sections were cut from several test blocks (+28 day cure) and a general overview follows.

(i) GP 20.8% f Thin Section (Photomicrograph 4)

Clasts-fragments are of two types: crystal aggregates 3-5 mm, and individual crystals 0.05-1 mm. The crystals are broken

Photomicrograph 4. Georgia Pacific Corp. Anhydrite Test Specimen with 20.8% Fines.

and cracked especially along prominent cleavage. The matrix in addition to the finer broken crystals above, is yellow brown, dark, fine grained without much crystal structure. Crystal boundaries are rounded but sharp without much penetration of the boundary either by staining or by recrystallization. The clast matrix boundary appears to be structurally weak.

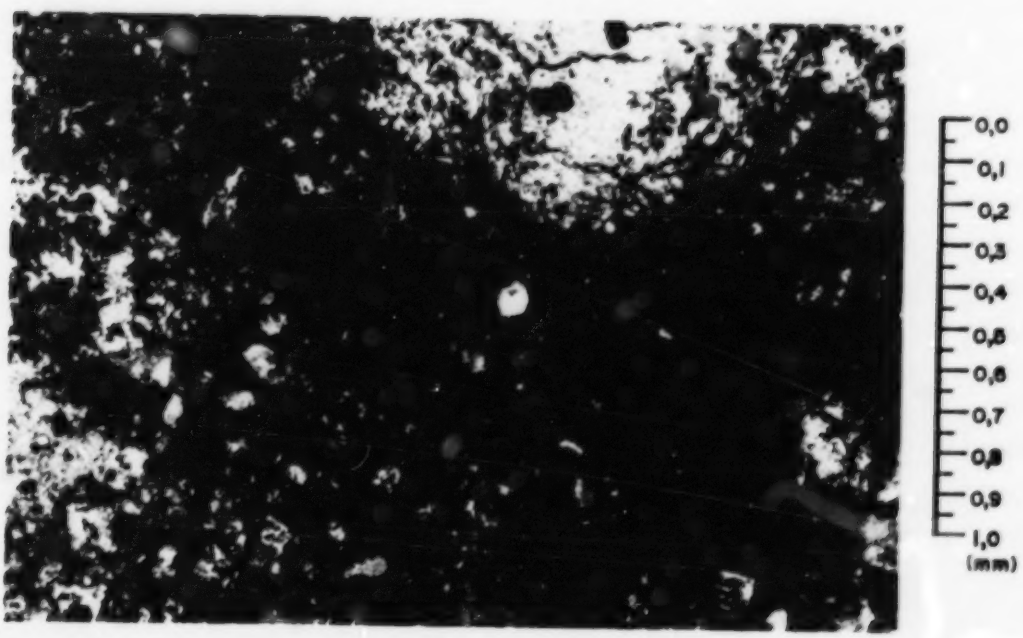
(ii) FG 24.7% f (Photomicrograph 5)

Clasts have embayed reaction stained zones up to 0.1 mm deep with fine grained matrix but up to 0.2-0.3 mm where the clast has the radial fibrous clusters. Boundary zones may be very diffuse. There appears to be abundant crystal structure in the matrix. The crystal-clast boundary appears to be moderately strong.

Photomicrograph 5. Fundy Gypsum C9. Ltd. Anhydrite Test Specimen with 24.7% Fines.

iii) LN 30% f Thin Section (Photomicrograph 6)

Clasts are subround to round, porosity is in part retained from the original rock plus additional bubbles. Matrix has a large amount of crystal structure 0.01-0.03 mm, with local brown stain and dusty nebulous material (nearly opaque). The clast-matrix boundary is well defined but embayed, intergrown and stained (up to 0.02-0.3 mm into the clasts). The boundary appears to be relatively strong.



Photomicrograph 6. Little Narrows Gypsum Ltd. Anhydrite Test Specimen with 30.0% Fines.

Other mixes of LN are illustrated for reference.

LN 24.7% f + 9% W+1% ACC. (Photomicrograph 7)

LN 20.7%f + 8% W+1% ACC. (Photomicrograph 8)

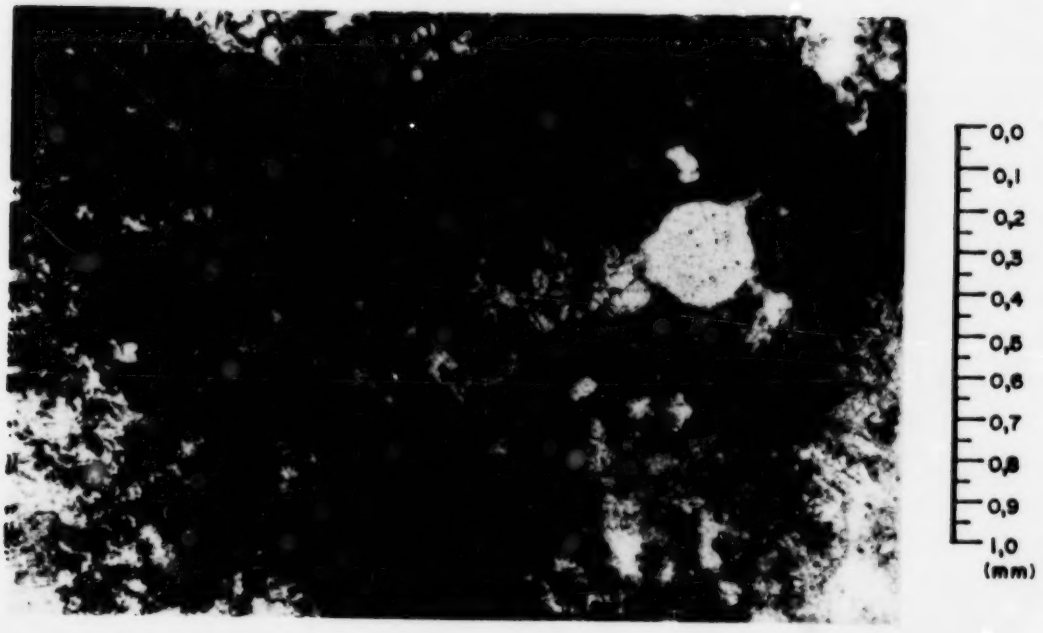
LN 30%f + 9.5% W+1.5% ACC. (Photomicrograph 9)

LN 30%f + 10.5% W+15% fly ash (Photomicrograph 10)

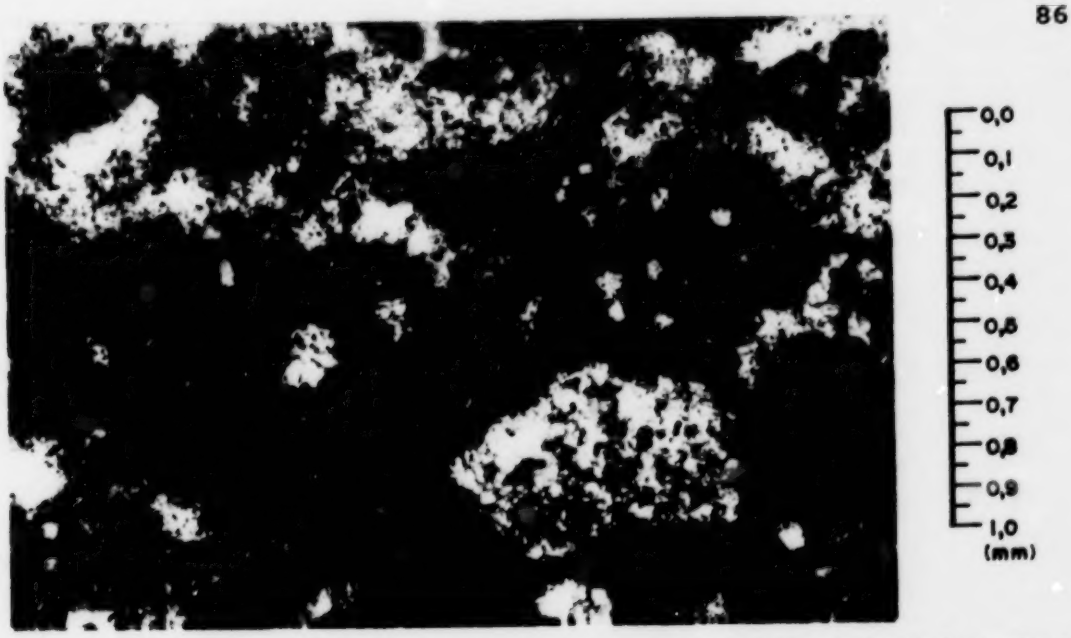
These are generally similar to LN 30% with the exception of LN 30% +fly ash which appears to have a darker finer grained matrix with abundant dark-opaque blebs (0.05-0.1 mm). The clast-matrix boundary is more diffuse. This sample generally resembles the SMA (France) sample (Photomicrograph 11).

Photomicrograph 7. Little Narrows Gypsum Co. Ltd. Anhydrite Test Specimen with 24.7% Fines, 1% Accelerator and 9.0% water.

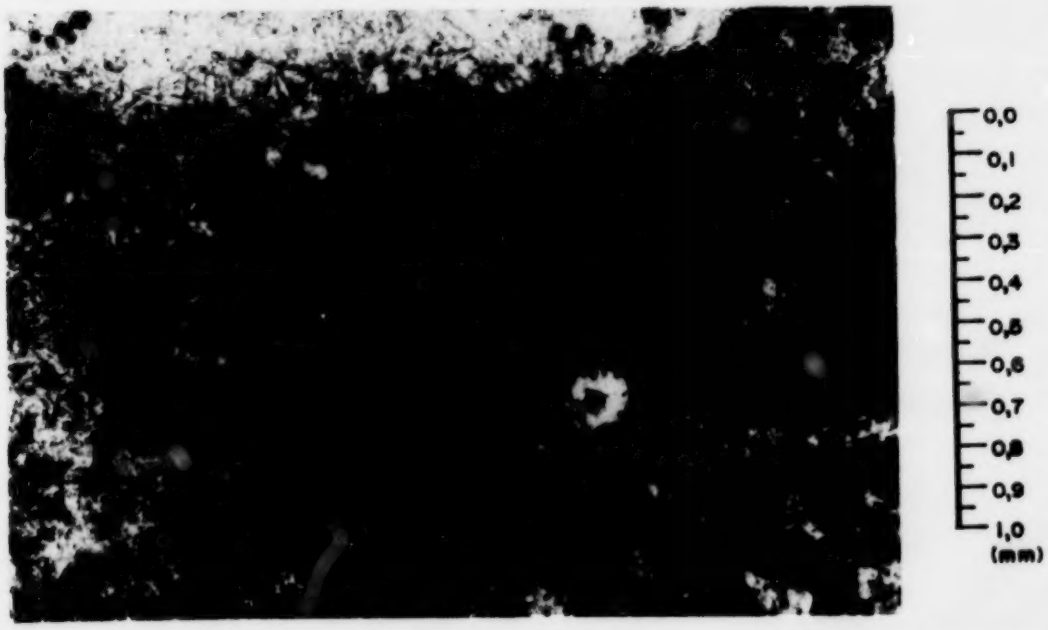
Photomicrograph 8. Little Narrows Gypsum Company Ltd. Anhydrite Test Specimen with 20.7% Fines, 1% Accelerator and 8% water.



Photomicrograph 9. Little Narrows Gypsum Company Ltd. Anhydrite Test Specimen with 30% Fines, 1.5% Accelerator and 9.5% water.



Photomicrograph 10. Little Narrows Gypsum Co. Ltd. Anhydrite Test Specimen with 30.0% Fines, 1% Accelerator, 15% Flyash and 10.5% water.



Photomicrograph 11. Proprietary anhydrite mix Test Specimen (SMA-France with 8.5% water.

6.4 Extended Analysis

Investigations were done to determine the distribution of accelerator through the matrix of the set anhydrite and to determine the amount of material converted to gypsum from anhydrite. Work was conducted on a scanning electron microscope equipped with an EDAX unit and an X-ray diffraction unit. This work did not produce meaningful results.

The SEM analysis was nonproductive because the low concentrations of accelerator were masked by the major presence of Calcium Sulphate. Consequently, mapping the accelerator location was impossible by this method. X-ray diffraction work was conducted to evaluate the conversion of anhydrite to gypsum. This technique provided only a preliminary assessment on the presence of gypsum in the hydrated anhydrite material. It was not possible to quantify the amount of gypsum by this method. Consequently, an analytical technique, whole-rock analysis, was used to quantify the anhydrite/gypsum quantities.

7. SUMMARY

This investigation has demonstrated that Nova Scotia anhydrites are suitable for use as construction materials in coal mines for gateside packs, stoppings, roadway backfilling, etc. Anhydrite samples from three of the four deposits that were tested (Little Narrows, Fundy Gypsum and National Gypsum) proved to be suitable candidates for this potential market. The Georgia Pacific anhydrite was not suitable because it failed to demonstrate adequate cementitious properties for these applications. The significant variations in anhydrite rock from each of these sites was outlined in the petrographic analysis section of this report.

A range of particle size tests were conducted with a major emphasis placed on the (-75 micron) fines size fraction. This work demonstrated that the strength of the anhydrite materials was increased with increased fineness of the -75 micron size fraction. It was concluded that the increased surface area of the finely ground product provided an increased number of sites for hydration reactions to occur and therefore increased the strength of the matrix. It is concluded that the % fines and more importantly the fineness of these particles must be controlled if successful results are to be achieved with Nova Scotia anhydrites. The addition of fly ash also proved to be beneficial to the set characteristics of the anhydrite material. The potential exists to continue work on this mix to further identify its potential.

A petrographic analysis of the cast anhydrite samples showed

that the stronger anhydrite materials exhibited significant intercrystal growth of the matrix into the coarser anhydrite crystals of the anhydrite mix. In comparison, the weak Georgia Pacific material exhibited no intercrystal growth between the matrix and the coarse anhydrite particles. It is therefore concluded that the rate of hydration of the fines to generate a matrix for the mix as well as the intercrystal growth between the matrix into the larger anhydrite (aggregate) crystals combine to determine strength of the anhydrite material.

The optimum water: solids ratio for Nova Scotia anhydrites was found to be consistent with European standard, with 8.5% water providing the strongest material. Water ratios up to 10% were examined and found to be acceptable. The humidity of the environment in which the specimens were cured had a significant effect on the strength of the material. Increased humidity retarded the drying phase of the crystal development and consequently delayed the development of strength. Though it was not investigated in this test program, a hot dry atmosphere will cause drying that is too rapid to allow proper hydration of the matrix and will significantly reduce the strength of the cured anhydrite material. Consequently, the mine atmosphere in which the anhydrite is used will affect the strength of this construction material. On general the dryer the mine atmosphere the stronger the anhydrite material will be. However, anhydrite should not be used in very hot, dry mines due to excessively fast drying that leads to weakened anhydrite structure.

The accelerators used in the detailed test program were restricted to a standard accelerator mix used in European anhydrite materials (1.8:1; ferrous sulphate heptahydrate: potassium sulphate). Preliminary tests with alternative ratios of these salts and different salts proved the European accelerator mix to be the most efficient. The volume of accelerator used ranged between 1% and 2% by weight of the dry materials in the mix. Tests were conducted to predict the size effect of the sample on the uniaxial compressive strength. It was shown that anhydrite pack structures will have a strength value equal to one-half the laboratory strength of a 40x40x62.5 mm test specimen. This relationship was confirmed to be generally accepted by European experts in anhydrite packing systems. It was shown that the conversion of anhydrite to gypsum was not a controlling factor in the development of mechanical strengths of hydrated anhydrite specimens. Other factors such as crystal structure of the matrix and intercrystal growth of the matrix into the anhydrite aggregate are very important.

8. RECOMMENDATIONS

Further testing of Nova Scotia anhydrite should now be done at a full-scale trial, to prove its application in coal mines. It is recommended to use Little Narrows anhydrite in this trial due to its superior performance in laboratory work.

It is imperative that the material for this trial be prepared to have approximately 30% fines with a specific surface area of approximately $0.25m^2/cc$, (corresponds to the 30 minute fine grind material). This size distribution is achieved in Europe using impact crushers. Any supplier in Nova Scotia should have to satisfy the requirements to prepare anhydrite in crushing facilities that will provide the required fines. It is recommended that sufficient samples of the crushed anhydrite product be tested in the laboratory to check the mechanical properties prior to use in a trial. A standard accelerator mix should be used at 1.5% by weight. If the equipment to premix the accelerator in the gauging water is available, it should be used. However, if the blended accelerator has to be dry-mixed with the anhydrite, thorough mixing should be used but if dust is an operating problem at this water concentration, water volumes up to 10% can be used.

It is recommended that a surface trial first be conducted in a shuttered pack hole area simulating the underground environment. This work will provide potential pneumatic stowing equipment operators with an introduction to the equipment. When

satisfactory results are achieved on surface, an underground trial should be implemented in an active longwall gateroad.

Pack design criteria should be established for the operation in which the trial is to be conducted. (It is noted that this work has been completed for Lingan Collery as Phase II of this report). During the underground trial, gateroad convergence measurements and pack loading history should be monitored for an evaluation of the anhydrite pack performance in the trial.

REFERENCES

Arauner, H. W., 1984; Strata Control with backfilling and Shotcreting, Gluckauf, Oct., 1984.

Arioglu E. and Dunham R. K., 1976; Physical Properties of Anhydrite/Accelerator Mixtures for Use as a Gateside Packing Material, Colliery Guardian, Jan. 1976, p. 31-33.

Blades M. J. and Daws G., 1974; Anhydrite Packing in the Ruhr Coalfield, Colliery Guardian, April 1974, p. 118-121.

Blom K. and Rohrs H., 1985; Experience with Packing material Mixtures of Natural Anhydrite and Electrostatic Precipitator Ash, Gluckauf, 1985.

British Gypsum, Technical Brochures

-ANAK for packs and stopping

-High Strength Anpak.

-Anpak - A.

-Anpak - B, High Strength spray Sealant. Manager, Mining Products - British Gypsum Ltd.

Cain P., 1985; Longwall Gateside packs: Part I - A Review of Packing Systems; March 1985, Division Report ERP/CRL 85-27(TR), CANMET, Energy Mines and Resources Canada.

Gluckauf, October, 1984; Consolidation of papers on hydraulic, cementitious backfill materials used in coal Mines.

Langley, W. S., Longley W. S. and Associates Ltd. Halifax, personal communication.

Nova Scotia Department of Mines and Energy, 1986; Annual Report for the fiscal year ending March 31, 1986, Nova Scotia Department of Mines and Energy, P 124.

Peng, S. S., 1978; Coal Min Ground Control, p. 215.

Roskill, 1987; The Ecomonics of Gypsum and Anhydrite, Fourth Edition, 1987, p. 4-7, 36-41.

Smart B. G. D., Davis D. O. and Somervill J., 1984; Application of the Roof-Strata-Tilt approach to Pack Design in an Arch-shaped Roadway, The Mining Engineer, Sept. 1984, p. 187-191.

Statham C. A., 1987; personal communications.

Wirsching F., 1978; Gypsum, Volume 12, Verlag Chemie, GmbH 28 pages.

Whittaher B.N. and Woodrow G.J.M., 1977; Design Loads for Gateside Packs and Support Systems; The Mining Engineer, Feb. 1977, p. 263-275.

ANHYDRITE PACK DESIGN CRITERIA FOR LINGAN COLLIERY, SYDNEY, NOVA SCOTIA

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September, 1989

1. INTRODUCTION

Research into the suitability of anhydrite as a pack material for use in the Sydney Coalfield has been carried out by McGill University, Montreal, and the Technical University of Nova Scotia (TUNS), Halifax. The Cape Breton Development Corporation (CBDC) has carried out surface trials in conjunction with anhydrite placement equipment suppliers.

The research has addressed the suitability of locally available anhydrites, the mechanical properties of various anhydrite, filler and accelerator combinations and the assessment and demonstration of placement equipment. The promising results of these investigations have lead to the proposal of a full scale underground trial of the packing method at Lingan Colliery.

The gateroad pack is arguably the most important member of the support complex in a longwall gateroad. It serves two functions; it protects the gateroad from the encroaching waste area, and it prev undue recirculation of ventilating air through the waste. It follows, therefore, that the design of the pack is an essential aspect in maintaining the productivity of the longwall panel.

The complexity of the interaction between the support and the strata in the face end region has hindered the application of engineering design principles to the dimensioning of packs. Recently, however, the roof-strata-tilt concept was developed in the U.K. The concept has been used very successfully at Lingan Colliery in the past and it is this method of pack design which has been used below.

2. PACK DESIGN

2.1 THE SUPPORT ENVIRONMENT

In front of an advancing coal face redistributed stresses cause the failure of the surrounding strata and the extrusion of the coal into the opening. Because no extraction has taken place at this point, there is little bed separation, although sliding along bedding planes is common. After the coal has been extracted the coal face is supported by the powered supports. At the face ends a pack is built adjacent to the gateroad. The immediate function of the pack is to support one end of the beam of rock delineated by the roof of the seam, the waste break off line and the base of the overlying bridging beds. This beam extends into, and is pinned in cantilever by, the ribside rock mass.

At this point the requirement for an early bearing pack becomes apparent. A weak pack will allow the roof beam to separate from the bridging beds. At some point the bending of the roof beam will generate tensile or shear failure over the rib, and the detached block will lower uncontrollably into the gateroad.

A correctly designed pack will prevent bed separation and will control the lowering of the roof beam in response to the subsidence of the overlying bridging beds. It will yield without losing strength until the redistributed stresses across the gateroad again reach equilibrium, at which point strata movement around the gateroad is virtually complete.

2.2 PACK STRATA INTERACTION

The dangers of a weak pack are those of uncontrolled convergence and total failure of the gateroad support. The development of a ribside shear break will concentrate abutment stresses close to the edge of the gateroad and cause floor heave.

A strong pack presents two dangers. The most likely danger is that the stresses generated in the pack and transmitted to the surrounding strata will exceed the bearing capacity of the roof or floor and cause penetration. Floor penetration will allow uncontrolled roof lowering and the development of a ribside break, along with the movement of floor material into the gateroad and the increased likelihood of floor heave. Roof penetration will first result in the development of a shear break adjacent to the pack. The truncated roof beam will then behave as an unsupported beam, resulting in gateroad support failure and floor heave.

With the acceptance of irresistible subsidence the second danger of a strong, stiff pack becomes apparent. If the load bearing capacity of the pack is reached before subsidence is complete, the pack will fail. In extreme cases, the load transferred from the failed element to adjacent elements will be sufficient to cause their immediate failure. The result, a chain reaction of pack failure, causes catastrophic loss of strata control and instantaneous destruction of the gateroad supports. Such a failure occurred in a gateroad packed using concrete blocks in the U.K., although the event has not been documented.

The object of pack design is therefore to develop sufficient resistance to control subsidence, but to ensure sufficient yield capacity to accommodate subsidence. The overall effect is therefore one of compromise, further tempered by the economic and production needs of the mine environment.

2.3 THE ROOF-STRATA-TILT CONCEPT

Extensive research into the deformation of gateroads at Betws Colliery in the U.K. identified the process of strata deformation in a longwall gateroad as the development of a subsidence profile in the roof beam extending over the coal rib, gateroad and pack (Smart et al, 1982). Although this initial work was conducted in rectangular gateroads, it has since been shown (Smart et al, 1984) that the principle also applies in arched gateroads.

The roof-strata-tilt concept of pack design centres on the notion that the tilt of the roof beam can be controlled by the installation of a pack of predetermined resistance. If the amount of tilt and the required resistance are known, then the pack design can be modified and a knowledge of pack material properties used to ensure that the minimum support resistance is maintained.

The design process is based heavily on in-situ monitoring results. Fortunately extensive research into pack behaviour has been carried out at Lingan Colliery, and most of the required information is available.

Design Procedure

2·4 DESIGN PROCEDURE

The recommended approach to pack design using the roof-strata-tilt concept is as follows;

- determine the bearing capacity of the roof and floor
- evaluate the load/deformation properties of the components to be used in the pack construction
- predict the subsidence profile which will generate load on the pack
- combine the pack compression due to the development of the subsidence profile with the load/deformation data to determine the total resistance developed by the pack
- modify the pack design if necessary to obtain optimum pack resistance and to eliminate the possibility of penetration of the roof or floor
- confirm that the resistance of the pack is sufficient to prevent a detached block from separating from the bridging beds.

These procedures are described below for the design of the trial anhydrite pack at Lingan Colliery.

3· DIMENSIONING OF ANHYDRITE PACKS

The design of the anhydrite pack for the Lingan trial is based on the design methods outlined above. It draws on experimental data on the mechanical properties of indigenous anhydrites determined by TUNS, experience with anhydrite packing in the U.K. and France and the results of in situ investigations at Lingan Colliery.

3·1 BEARING CAPACITY

The determination of the bearing capacity of the roof and floor of the pack hole is an important part of the pack design procedure. The stresses generated in the pack are directly transmitted to the roof and floor material. If these materials fail under the applied stresses, then pack penetration will occur and strata control will be lost.

Bearing capacity determinations are routinely undertaken in civil engineering foundation design, and the theory is easily transferable to pack design. However, in-situ determination of bearing capacity is recognised as an important contribution to the design process if facilities are available. In-situ bearing tests were conducted at Lingan Colliery, but for the reasons given below, the results were disappointing. As a result, laboratory testing of the floor material was undertaken to provide input data for the theoretical determination of bearing capacities.

3·1·1 In-situ Testing

The bearing capacity tests undertaken at Lingan Colliery were the first such tests to be done in the coalfield. The only equipment available, fromthe Coal Mining Research Centre (CMRC) in Alberta, was rented and flown to Halifax. The equipment supplied was as follows;

- Enerpack RR10013 100 ton capacity double acting hydraulic cylinder
- 203.2 mm diameter, 12.2 mm wall structural steel column sections (CSA G40.21-50W, 222kN yield) of 1.2 m, 0.9 m, 0.6 m, and 0.3 m lengths. The sections were bolted together through flanges to form a column with a design capacity of 890 kN at 6.4 m length.
- top bearing plate, 304 mm x 457 mm x 25 mm, and bottom load plate 304 mm square and 25 mm thick.
- miscellaneous hoses, gauges and fittings.

An Enerpack hand pump rated at 70 MN/m^2 was supplied by TUNS.

The plate size had been selected by CMRC on the basis of tests undertaken by the United States Bureau of Mines (USBM, 1970) which showed that results using a 304 mm square plate gave good results for bearing capacity without the need for extrapolation.

The equipment was transported to Sydney, Nova Scotia, where arrangements were made to take it underground.

The site for in-situ testing had to be carefully chosen. The test equipment was extremely heavy, bulky and therefore difficult to transport. Materials handling in five of the six gateroads at Lingan Colliery was by hand from the railhead some 50 m from the face end where the tests were to be conducted. The 7 West packhole was selected because a monorail was installed between the railhead and the face end to transport materials.

Testing was conducted in the packhole 7.2 m behind the faceline. The pack area was characterised by a strong pale coloured fine grained medium bedded sandstone roof. The immediate floor comprised 0.8 m of strong, massive sandstone seatearth, underlain by a weaker, mudstone seatearth with rootlets and listric surfaces, of unknown thickness.

Two tests were conducted, the results of which are shown as bearing pressure against deformation in Figure 1. The first test was conducted on about 10 mm of fine coal on a flat area of packhole floor. Timber packing was used between the top plate and the roof. The second test was conducted approximately 1 m away from the first site, but with no timber above the top plate. In both tests load was measured indirectly from the hydraulic pump pressure and applied in 1.38 MN/m^2 increments to 68.96 MN/m^2, representing a final bearing pressure of 9.58 MN/m^2. Deformation was measured from the expansion of the hydraulic ram using a dial gauge to a precision of 0.01 mm.

The graphs in Figure 1 show that at maximum bearing pressure, 9.58 MN/m^2, failure had not taken place in either test. The low deformation modulus in Test 1 is a result of the crushing of the wood packing. During Test 2 loosening of the supports in the packhole was noticed as the applied load reached approximately 75% of maximum, implying that a loosened block of strata lying over the pack area was being lifted by the test column.

It is therefore concluded that the ultimate bearing pressure of the immediate floor in the 7 West pack area is in excess of 9.58 MN/m^2. However, because of the limitations imposed by the equipment and the test period, actual bearing capacities were not determined. In order to accomplish failure of the floor material in subsequent tests, redesigned equipment, lighter in construction and more easily used in the close confines of a face end environment, should be constructed and used with a series of smaller bearing plates.

In order to confirm the in-situ test results samples of the immediate floor and sub-floor were removed to the TUNS rock testing laboratory.

3·1·2 Laboratory Testing

Floor specimens returned from the field were sub-cored and tested to ASTM standards. The immediate floor was subjected to uniaxial compressive, triaxial and direct shear testing. The sub floor was test in uniaxial compression and direct shear. Table 1 gives the results of the various tests, which are illustrated in Figure 2. The angle of internal friction and cohesive strength were determined from the Mohr envelope resulting from the triaxial tests, and also from the direct shear tests.

Determination of the angle of internal friction and cohesive strength from the Mohr envelope was by measuring the gradient of the envelope and its intersection with the shear axis respectively. The direct shear test results however confirmed that the shear strength of both materials was dependent upon the normal stress, especially at the low normal stresses used in the tests. At higher stress levels, however, the shear stress/normal stress ratio decreased and adopted a flatter shape. The cohesive strength of the material can be determined from the intercept of this flatter section with the shear stress axis. However, the graphs did not extend far enough for the extrapolation to be done, so the angle of friction was determined from the residual direct shear curves and tangents to the pack shear curves drawn to intersect the shear axis to give the cohesive strength. These values were 7.93 MN/m^2 for the immediate floor and 3.89 MN/m^2 for the sub-floor. The value for the immediate floor was lower than that determined from the triaxial testing and so will be used in the theoretical determination of the bearing capacity. The internal friction angles measured for the immediate floor were similar at 31 and 33 degrees, and the sub floor friction angle measured from the direct shear tests was also 33 degrees.

3·1·3 Theoretical Bearing Capacity

There are many theories from which the bearing capacity of the strata can be determined. Coates (1981) described the bearing capacity, q_b, of a strip foundation to be;

$$q_b = 0.5 \cdot d \cdot B \cdot f^{5/2} + C \cdot (f-1)(f+1) - 0.5 \cdot d \cdot B \cdot f^{1/2}$$

where d = density of floor material
C = uniaxial compressive strength
B = width of foundation
and $f = \tan^2(45 - \phi/2)$.

For ϕ = 33 degrees, f = 3.124, therefore;

$$q_b = 0.22 \cdot B + 8.76\, C - 0.022 \cdot B$$

Since B is in practice very small ranging from 1 to 3 for conventional monolithic packs, $q_b = 9C$ as a conservative rule of thumb. This gives a bearing capacity of 756 MN/m^2. Farmer (1982) quotes a similar rule of thumb where;

$$q_b = 9 \cdot c$$

where c is the cohesive strength of the material. In this case the bearing strength of the floor will be 79 MN/m^2.

Brady and Brown (1985), when discussing the bearing capacity of the floor beneath a pillar, suggested that the bearing capacity can be represented as;

$$q_b = 0.5 \cdot d \cdot B \cdot N_g \cdot S_g + c \cdot \cot\phi \cdot N_q \cdot S_q - c \cdot \cot\phi$$

where N_g and N_q are functions of ϕ and S_q and S_g are shape factors, given as follows;

$$N_q = e^{(pi \cdot \tan\phi)} \cdot \tan^2(45 + \phi/2)$$
$$N_g = 1.5 \cdot (N_q - 1) \cdot \tan\phi$$
$$S_g = 1 - 0.4 \cdot (B/l)$$
$$S_q = 1 + \sin\phi \cdot (B/l)$$

where l is the length of the pillar.

If the pack is considered as a long thin pillar both S_g and S_q approach the value of 1.0. If individual packs are considered, B/l is approximately 1 and S_g and S_q are 0.6 and 1.54 respectively. Substituting the given values in the rest of the equation, for a long pack, q_b = 306 MN/m^2 and for individual packs, q_b = 478 MN/m^2

Despite applying the recommended safety factor of 2, these are very much higher than the rule of thumb determined by Farmer.

Couetdic and Barron (1984) published a comparison of bearing capacity formulae, expressing the relationships between the ratio q_b:uniaxial compressive strength against the angle of internal friction for each equation as shown in Figure 3. Selecting ϕ = 33 degrees, then the range of values of q_b is from 2.3 C to 30.48 C, depending on the bearing capacity formula selected.

The uniaxial compressive strength of the immediate floor was detrermined as 84.5 MN/m^2. Kulhawy and Goodman (1987) suggest that the in situ strength of the rock for bearing capacity calculations is one third of the laboratory strength. In this case, the bearing capacity of the immediate floor lies in the range 64 - 848 MN/m^2.

3·1·4 Summary

In situ bearing capacity tests failed to induce failure in the floor material at bearing stresses of 9.58 MN/m^2.

Laboratory testing and theoretical determinations of the bearing capacity resulted in values of 64 to 848 MN/m^2. Adopting a safety factor of two (Brady and Brown, 1985; Kulwahy and Goodman, 1987) and the lowest determined value of q_b, it is suggested that a maximum floor bearing stress of 32 MN/m^2 is adopted for the immediate floor. Based on a similar analysis, the allowable bearing stress for the sub-floor is recommended to be 13.8 MN/m^2.

3·2 PACK MATERIAL PROPERTIES

Fundamental to the design process is the determination of the properties of the pack materials, specifically the strength time curve and the deformation properties. Laboratory studies conducted at TUNS have indicated appropriate mix ratios, strength development rates and stress/strain relationships for Nova Scotian anhydrites. Unfortunately, no data is available for the in situ properties of the materials, so published data from France and the U.K. have been used as baseline figures.

3·2·1 Properties Of Nova Scotian Anhydrites

Samples of anhydrite from Little Narrows, National Gypsum and Fundy Gypsum were tested at TUNS and evaluated against each other and against a proprietary imported anhydrite packing material (the Knauf product) used in the surface trials at Lingan Colliery. Initially the local materials did not achieve adequate strengths, especially in the hours immediately after mixing, but when the size distributions were adjusted to compare with the 20.7% fines (-75 microns) of the Knauf product, all the local anhydrites proved acceptable, although the Little Narrows material was chosen for subsequent testing (Jones and Payne, 1988).

Figure 4 illustrates the strength development with time of four sample sets. Curves 1,2 and 4 are the results of tests on 40 x 40 x 62.5 mm blocks, whilst curve 3 was obtained from the testing of 101.6 mm cubes. The strength development curves of the Knauf product (1 and 3) are very similar to those of the Little Narrows blend.

The results of stress strain determinations on the Knauf cube specimens are shown in Figure 5. The elastic modulus increases at a rate of 55 MN/m^2 per hour for 48 hours and at 160 MN/m^2 per day after that. Although stress strain curves were obtained for some tests on the smaller specimens, the specimen size is considered too small to allow their wider application. Indeed, as will be shown below, the values obtained for the Knauf product are very much higher than those obtained for in-situ anhydrite packs.

3.2.2 Properties Of Other Anhydrites

Results from the in situ monitoring of anhydrite packs in the UK and France were obtained to compare with the laboratory results.

Easington Colliery, U.K. (Adam et al, 1977)

Anhydrite packs 1.6 m high and 1.5 m wide were set in gateroads serving the J74's advancing face in the Low Main Seam at a depth of 520 m. Pack load reached 5 MN/m^2 at 5% strain after approximately 35 m of face advance, and dropped to 4 MN/m^2 thereafter. The roof and floor were relatively strong. The in situ modulus was 100 MN/m^2 over the first 35 m of face advance.

Parkside Colliery, UK. (MRDE, 1982)

Anhydrite packs 1.5 m high and 1.5 m wide were set in a gateroad serving the T24's advancing face in the 1.6 m thick Trencherbone seam at a depth of 735 m. The anhydrite was part of a three element pack which also included a 0.9 m wide concrete block waste chock and a 2.8 m wide section of debris filled hessian sacks, with the anhydrite section at the gateroad edge. The roof and floor were weak. The anhydrite strength was measured as 28 MN/m^2.

The in situ results from Parkside showed delayed load acceptance on the anhydrite elements at the three sites monitored, undoubtedly due to the resistance offered initially by the waste chock. However, when the anhydrite elements did begin to accept load, the in-situ modulus could be determined at two sites, with values of 40 MN/m^2 and 97 MN/m^2.

Provence, France (CERCHAR, 1983)

Anhydrite packs 3.0 m in height and 1.8 m in width were set over a 25 m trial zone in the Quartier de L'Etoile of Houilleres de Provence. The maximum pack load recorded was 9 MN/m^2 at 2.6% strain giving an in situ modulus of 290 MN/m^2.

In these trials a series of laboratory tests was also carried out comparing laboratory mixed specimens with those obtained during pack placement. The latter set of samples gave higher strengths, attributed to compaction on ejection from the delivery nozzle. The results of these tests are shown in Figure 6.

The in situ deformation behaviour of the pack exhibited failure along planes corresponding to the angle of repose of the wet anhydrite (40 - 50 degrees). This may have been brought about by separation of the particle sizes in the pneumatic pipeline.

3·2·3 Summary

The data described above shows a very wide range of information and emphasizes the importance of in situ data collection during the Lingan trial.

The two most important factors are the deformation modulus of the packing material and the strength development with time. Because of the range of data, a composite must be used. Figures 6 and 7 show the all the values obtained for strength development and in-situ modulus respectively. The laboratory modulus values have been omitted as they are unrepresentative on the basis of the in situ results.

3·3 SUBSIDENCE PROFILE

3·3·1 Gateroad Deformation

Gateroads serving advancing longwall faces at Lingan Colliery deform in a predictable manner. The absence of support to the strata on the waste side allows the roof beam to tilt over the pack whilst still supported by the coal rib. This is frequently shown by the extreme deformation of the arch legs on the pack side of the gateroad.

Deformation is most easily measured by installing point anchored roof bolts in the roof and floor at three points across the gateroad. Repeated measurements between each pair indicate differential convergence. Pack closure struts indicate the amount of closure in the pack. Where the distance between each of the measuring stations is known, the differential convergence can be used to determine the progression of roof-strata tilt and the location of the pivot point in the ribside.

3·3·2 Previous Experience At Lingan Colliery

The prior recognition of the importance of packing as a factor in the stability of gateroads at Lingan Colliery has ensured the collection of a considerable quantity of in situ data. In particular the investigation of the effects of the change from wooden chock packs to a monolithic pack (Cain, 1987) resulted in the determination of subsidence development represented by roof beam tilt and the progression of the pivot point into the ribside (Table 2). The variation in pivot point location is a result of the interaction of the pack support, roadway support and the support developed by the ribside.

3·3·3 Summary

Based on in situ data form previous site monitoring at Lingan the form of the roof beam tilt profile can be determined. It should be noted that past analyses have determined that the amount of tilt increases with

respect to the thickness of extraction. At Lingan Colliery the extracted heights vary from 1.5 m on the West side to 2.1 m on the East side. For conservative design results the subsidence due to maximum extraction is considered for the two pack height discussed later.

3·4 PACK RESISTANCE GENERATION

Pack resistance is generated as a result of the effect of closure of a pack of a certain stiffness. It is expressed in MN/m run of roadway. For example, a 2 m wide pack in which the average stress applied by the lowering of the roof is 10 MN/m^2 will have a resistance of 20 MN/m.

Conversely, if the modulus of a pack element, E (N/m^2), and the closure of that element, k (m), are known, then the resistance of that element, r, is given by;

$$r = E \,.\, k/h \,.\, w \,.\, 10^{-6} \text{ MN/m}$$

where h = original height in metres
and w = the width of the element in metres.

The total resistance of the pack is simply the sum of the resistances of each element.

3·4·1 Previous Experience At Lingan Colliery

Pack resistance calculations have been performed at five locations at Lingan Colliery. Studies in the 6 West and 9 East tailgates (Ross and Cain, 1985) showed that a pack resistance of 6 MN/m achieved after 15 m of face advance produced a stable gateroad, whereas a resistance of 1.5 MN/m after the same distance, rising to 4 MN/m after 70 m advance gave an unstable roadway.

The reported value of pack resistance in the 8 East Coal Road, (Cain, 1985) was between 6.75 and 8.25 MN/m, whilst in the 9 East Coal road the pack resistances were between 5.85 and 6.3 MN/m.

For reasons of increased safety, a minimum pack resistance of 8.25 MN/m will be adopted in the dimensioning of the trial anhydrite pack.

3·5 PACK DESIGN

Two pack designs will be considered based on the data given above. Firstly a 1.5 m high pack on a strong floor, and secondly a 2.1 m high pack on the weak floor material. An initial pack width of 1.5 m will be considered in both instances, and it will be assumed that the centre of the pack is located 6 m from the ribside, in line with current roadway dimensions at Lingan Colliery.

The data in Table 2 can be used to determine pack strains fro both extractions considered to be calculated, as in Table 3.

There is now sufficient information available to calculate the resulting pack loads, and hence the pack resistance. The in situ strength development is assumed to be 50% of the laboratory strength development values obtained for the composite strength development curve to allow for variations in strength with sample size. The deformation modulus used has been calculated from the maximum strength allowed, 14.5 MN/m^2, assuming a 5% failure strain, i.e. 270 MN/m^2. A residual strength of 7 MN/m^2 has been applied after failure. Using this information the development of pack strain, pack stress and pack resistance are shown in Figure 8.

The graphs indicate that on the strong floor a 1.5 m wide pack will provide adequate resistance and will not penetrate the floor. The ultimate bearing stress is 14.5 MN/m^2, well below the calculated maximumof 32 MN/m^2. The minimum value of pack width to give the required resistance is 1.15 m, but the wider pack is preferred for increased stability.

In the case of a 2 m extraction over a soft floor the results indicate that the resistance is adequate but the bearing stresses will exceed the maximum allowed value of 13.8 MN/m^2, although only by a small amount. Despite the safety factors already introduced to the design process, it is recommended that either the pack material be modified to result in a lower strength, or that a the load developed in the pack is spread over a wider base area. Construction of a pack 1.9 m at the base and 1.5 m wide at the roof would achieve the required objective, but may be too difficult to realise in practise.

3.5.1 Detached Block Calculation

(after Whittaker and Woodrow, 1977)

A detached block forming over the gateroad at the face end is assumed to extend horizontally from the rib side to the waste edge (in this case 6.75 m) and from the roof of the seam to the base of the bridging beds. The base of the bridging beds is assumed to be a plane located at a distance of twice the extracted height from the roof of the seam, in this case between three and four metres. Taking the higher value and a rock density of 2.6 tonnes/m^3, the weight of the block formed will be 70.2 tonnes for each metre of gateroad. The pack must therefore exert a resistance of 2.06 MN/m^2 to resist the separation of this roof block, a level which is achieved after 1 - 5 metres advance. The roof block will therefore not detach.

4. SUMMARY

The design process selected above and worked through with the in situ data from Canada and Europe indicates that a pack width of 1.5 m is suitable for the support of gateroads serving both 1.5 m and 2.0 m extractions, but that in the softer floor conditions either weaker pack materials or an extended pack base are required to prevent floor penetration. However, several facts should be considered.

Firstly, it must be recognised that the data used to define pack strengths and moduli were very poor, and although the assumptions used in the design process result in reasonable values, there can be only a low order of confidence placed on the results without further in situ work.

Secondly, previous in situ data indicates anhydrite pack failures before face advances of 5 m. The post failure properties of the anhydrite are not well represented in any of the examples reviewed. Again, in situ results are required.

Thirdly, the modification of the subsidence profile, at least in the short term, by the application of a stiffer pack cannot be ruled out. In fact, it is reasonable to assume that it will occur. In this case, the results calculated above will not be representative.

These comments serve to emphasize the fact that, while the initial pack design should conform to that given, the success of the trial will depend upon the continuous monitoring of the in situ behaviour of the packing material and its results on the deformation of the gateroad

5. RECOMMENDATIONS

The application of new packing technology in so complex an environment requires the closest scrutiny and control. Past changes in pack design have only been successful as a result of the full preliminary examinations and extensive in situ monitoring undertaken. It is not surprising, therefore, that the fundamental recommendation of this report is that similar extensive monitoring accompanies the anhydrite trial programme based on the following;

- before the trial starts, a series of at least two full monitoring sites should be established in the trial gateroad to determine the deformation, subsidence and pack resistance characteristics.
- local determination of floor bearing capacity should be undertaken if the floor lithology varies from that observed in the 7 West Coal Road. A smaller, lighter unit should be developed for use with a variety of bearing plate sizes. In addition, an examination of the response of the two floor strata under pack loading using numerical methods might be appropriate to determine the extent of any failure of the sub-floor.
- parameters determined from in situ monitoring should be used to verify the pack design concluded above. Close attention must be paid to any variation in material properties.
- monitoring of the trial packs should be undertaken at at least two sites, and the design verified once more. Pack material composition and properties in situ must be constantly monitored to en sure consistency with the standard product.
- any variance from anticipated gateroad behaviour must be evaluated and if necessary corrected by modification of the pack design.

6 ACKNOWLEDGMENTS

Thanks are due to Dr D.S. Jones, formerly of TUNS but now at the Nova Scotia Department of Mines and Energy, and to Mr D. Payne, also formerly at TUNS, now employed as a Mining Engineer by CBDC.

In addition the management and staff at Lingan Colliery, the General Mining Building headquarters of CBDC in Glace Bay and the CANMET Coal Research Laboratory in Sydney Nova Scotia gave invaluable help and advice.

REFERENCES

Adam, G.J. et al
"Stability of Access Tunnels to Coal Mine Excavation."
Paper presented to the Conf. on Rock Engng. University of Newcastle upon Tyne, 4-7th April, 1977.

Brady, B.H.G., Brown, E.T.
"Rock Mechanics for Underground Mining"
Pub. by Allen and Unwin, London, 1985.

CERCHAR
"Houilleres de Provence: Essai de Traitement d'arriere Taille par epi d'anhydrite, Quartier de L'Etoile, Voie 22 Sud Taille 09 - Compte Rendu des Mesures Effectuees."
Laboratoire de Mecanique des Terrains, 83(1) 11-72-1050 No 2 NK, February, 1983.

Cain, P.
"Determination of the Required Pack Width for a Monolithic Pack Installation in the 9E Coal Road, Lingan Colliery"
CANMET Divisional Report Series ERP/CRL 85-35(TR)

Cain, P.
"Improvements in Pack Design at Lingan Colliery"
CANMET Divisional Report Series CRL 87-45(IR)

Coates, D.F.
Rock Mechanics Principles."
Department of Energy Mines and Resources Canada, Monograph 874, Revised 1981.

Couetdic, J.M., Barron, K.
"Plate Load Testing as a Method of Assessing the In Situ Strength Properties of Western Canadian Coal."
Department of Energy Mines and Resources Canada, Mines Branch/Mining Research Centre Divisional Report 74/93, July 1974.

European Communities Commission
"Study of yield zones around gateroads: Final Report on ECSC Research Project 7220-AC/812"
British Coal HQ Technical Services (formerly MRDE) 1983

Farmer, I.W.
"Deformation of Access Roadways and Roadside Packs in Mines."
Proc. of the Symp. on Strata Mech. Department of Mining Engineering, University of Newcastle upon Tyne, 5-7th April, 1982.

Jones. D.S., Payne, D.
Personal communication, 1988.

Kulhawy, F.H., Goodman, R.E.
"Foundations in Rock."
In Ground Engineers Reference Book, Ed. F.G. Bell, Butterworths, 1987.

MRDE
"Retreat Working in the Trencherbone Seam at Parkside Colliery using an Anhydrite Packed Roadway a Second Time."
British Coal H.Q. Technical Services (MRDE) Internal Report No 82/6.

Ross, S.D. and Cain, P.
"The effectiveness of new tailgate support methods at Lingan Colliery"
CANMET Divisional Report Series, ERP/CRL 85-107(IR).

Smart, B.G.D. et al
"Pack Design Criteria at Betws Colliery"
Trans I. Min E. July 1982 pp15-22

Smart, B.G.D. et al
"Application of the Roof Strata Tilt Concept to Pack Design In an Arch shaped roadway"
Trans I.Min. E. September 1984 pp187-192

USBM
"In situ Tests of Bearing Capacity of Roof and Floor in Selected Bituminous Coal Mines."
U.S. Department of the Interior, Bureau of Mines, RI 7406, 1970.

Whittaker, B.N., Woodrow, G.J.M.
"Design Loads for Gateside Packs and Support systems"
Trans I. Min. E. February 1977 pp 263-275.

TABLE 1: SUMMARY OF LABORATORY TEST RESULTS

Uniaxial/Triaxial Testing

Material	Axial Stress MN/m^2	Confining Stress MN/m^2	Cohesion MN/m^2	Angle of Internal Friction
Immediate Floor	83.5	0	24.14	31
	112.47	9.65		
	189.47	34.48		
Sub Floor	43.0	0	Not Determined	Not Determined

Direct Shear Testing

Material	Peak Shear Stress MN/m^2	Residual Shear Stress MN/m^2	Normal Stress MN/m^2
Immediate Floor	5.07	--	1.93
	8.86	2.62	3.93
	11.79	4.24	5.86
	12.55	4.52	7.93
Sub Floor	4.82	1.79	1.93
	6.41	3.17	3.93
	6.72	3.62	5.86

TABLE 2: BEAM TILT AND PIVOT POINT LOCATIONS

Distance From Face (metres)	Beam Tilt (degrees)	Rib Closure (mm)	Pivot Point Location (mm from Rib Bolt)
5	0.43	45	5881
10	0.63	94	8548
20	1.45	198	7822
30	2.08	285	7847
40	2.61	343	7524
50	2.86	385	7706
60	2.90	413	8152
70	2.85	437	8778
80	2.86	452	9047
90	2.90	462	9120
100	2.93	471	9197

TABLE 3: PACK STRAIN CALCULATIONS

Distance From Face (metres)	Beam Tilt (degrees)	Pivot Point Location*	Pack Strain (%) Calculated for 1500mm Pack	Pack Strain (%) Calculated for 2000 mm Pack
5	0.43	6381	6.19	4.65
10	0.63	9048	11.03	8.27
20	1.45	8322	24.17	18.13
30	2.08	8347	34.74	26.05
40	2.61	8024	42.62	31.96
50	2.86	8206	47.31	35.48
60	2.90	8652	49.48	37.11
70	2.85	9278	50.70	38.03
80	2.86	9547	51.77	38.83
90	2.90	9620	52.75	39.56
100	2.93	9697	53.56	40.17

* Distance from the rib, in mm, obtained by assuming 500 mm from rib bolt to rib side.

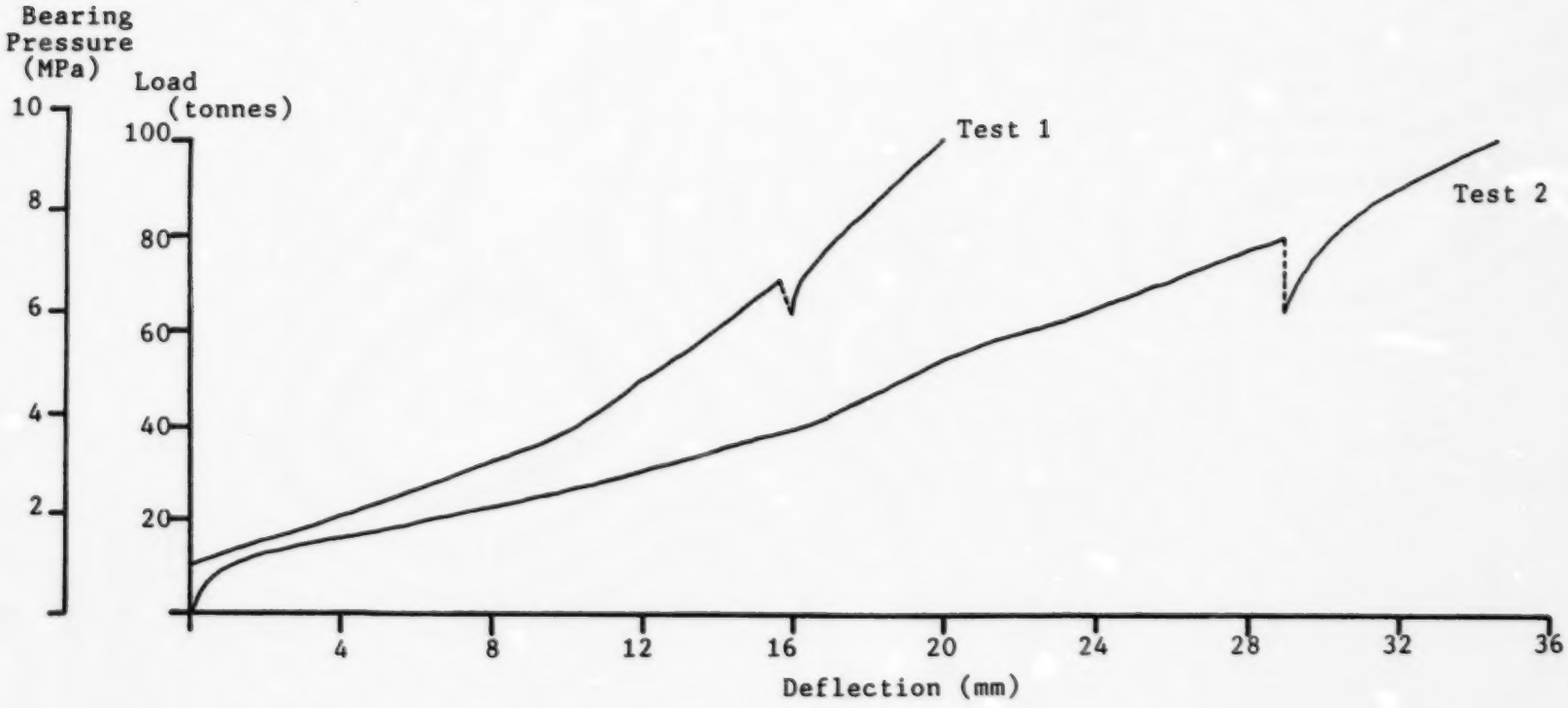
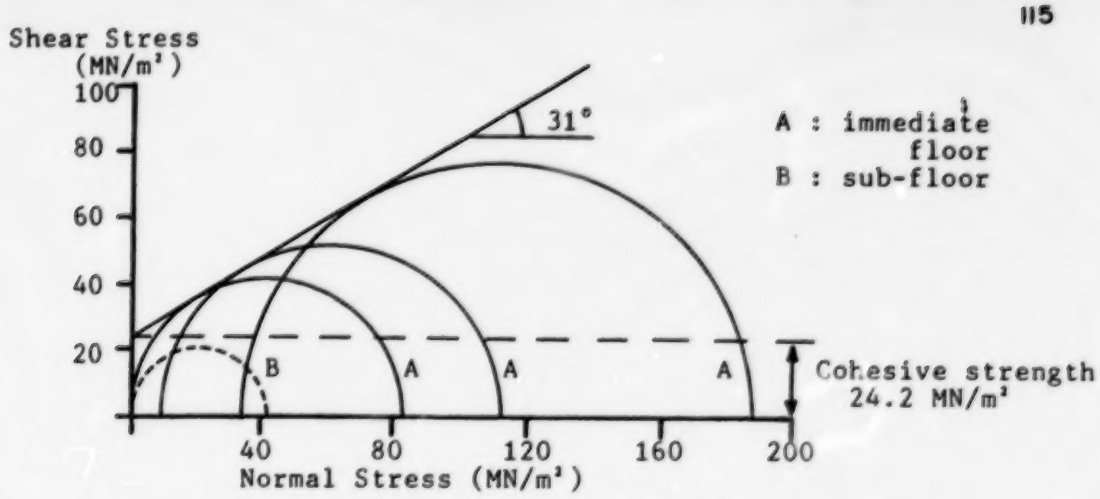
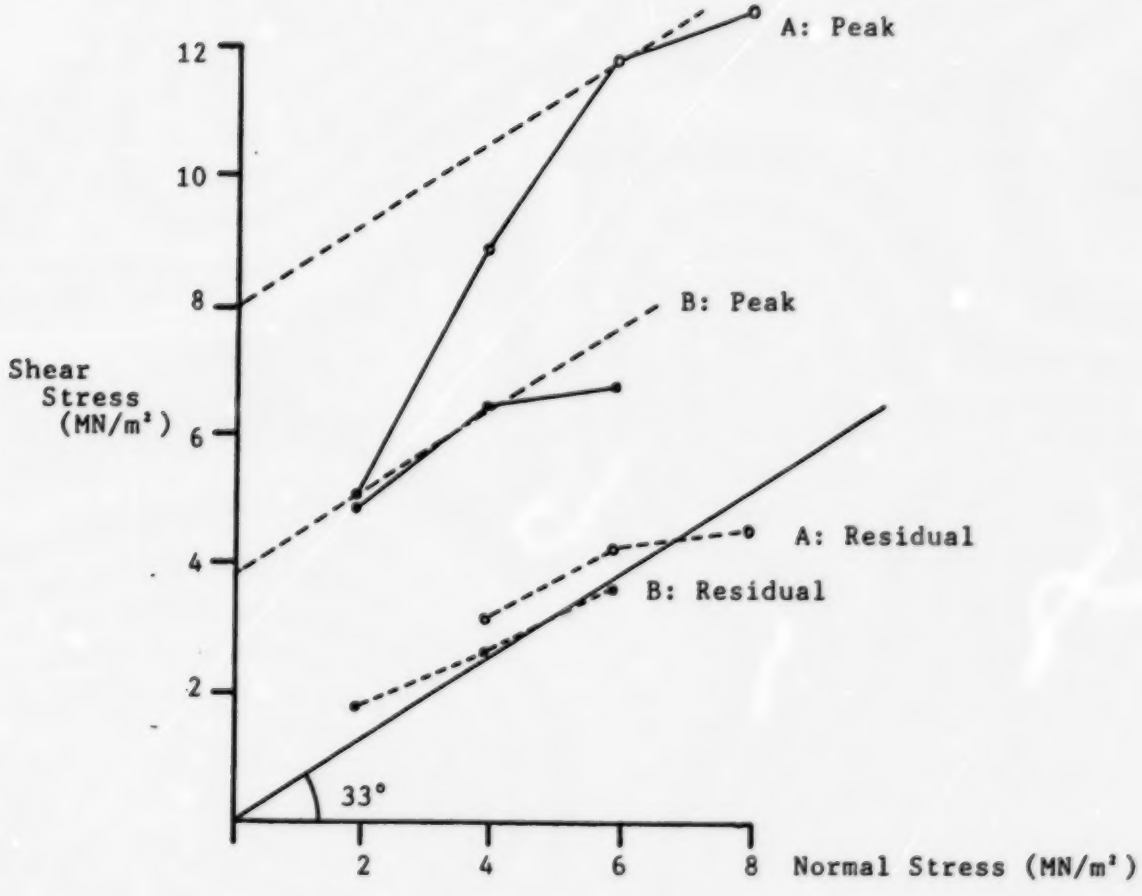


FIGURE 1: IN SITU BEARING PRESSURE RESULTS



(a) Uniaxial/Triaxial Testing Results



(b) Direct Shear Testing Results

FIGURE 2: RESULTS OF LABORATORY TESTING

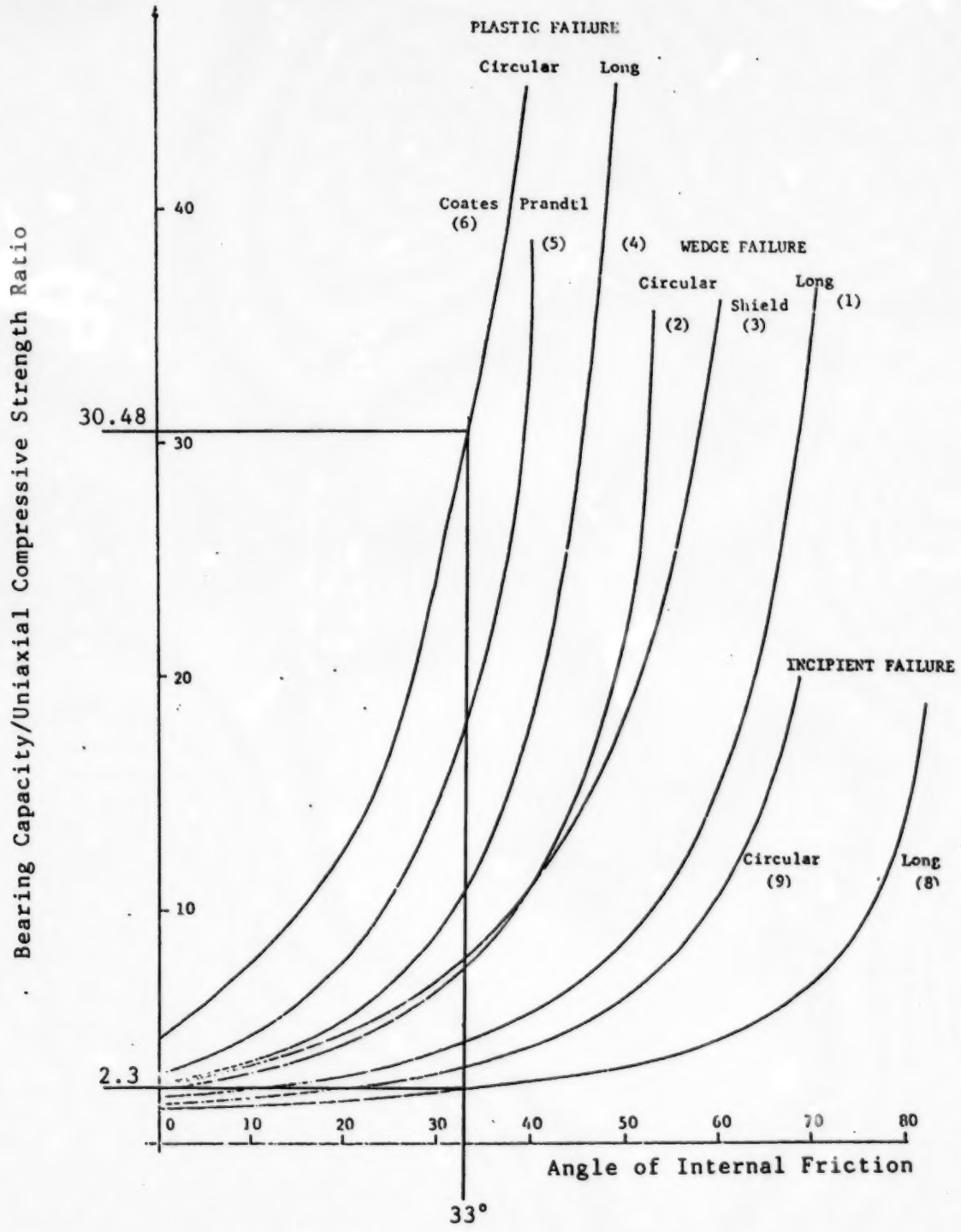


FIGURE 3: RELATIONSHIP BETWEEN BEARING CAPACITY, STRENGTH AND FRICTION ANGLE (after Couetdic and Barron, 1984; numbers refer to source text references)

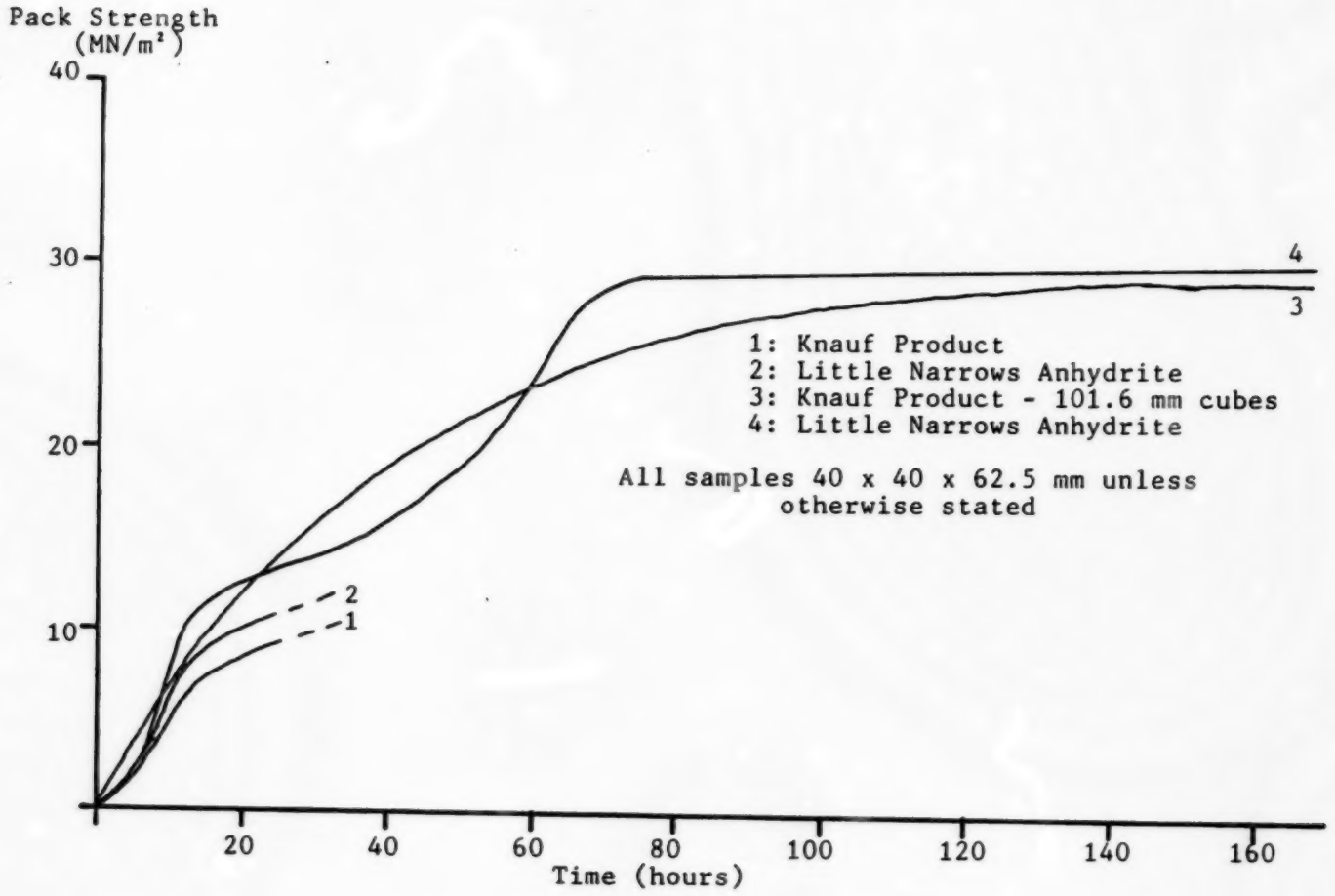


FIGURE 4: STRENGTH DEVELOPMENT OF TEST ANHYDRITES

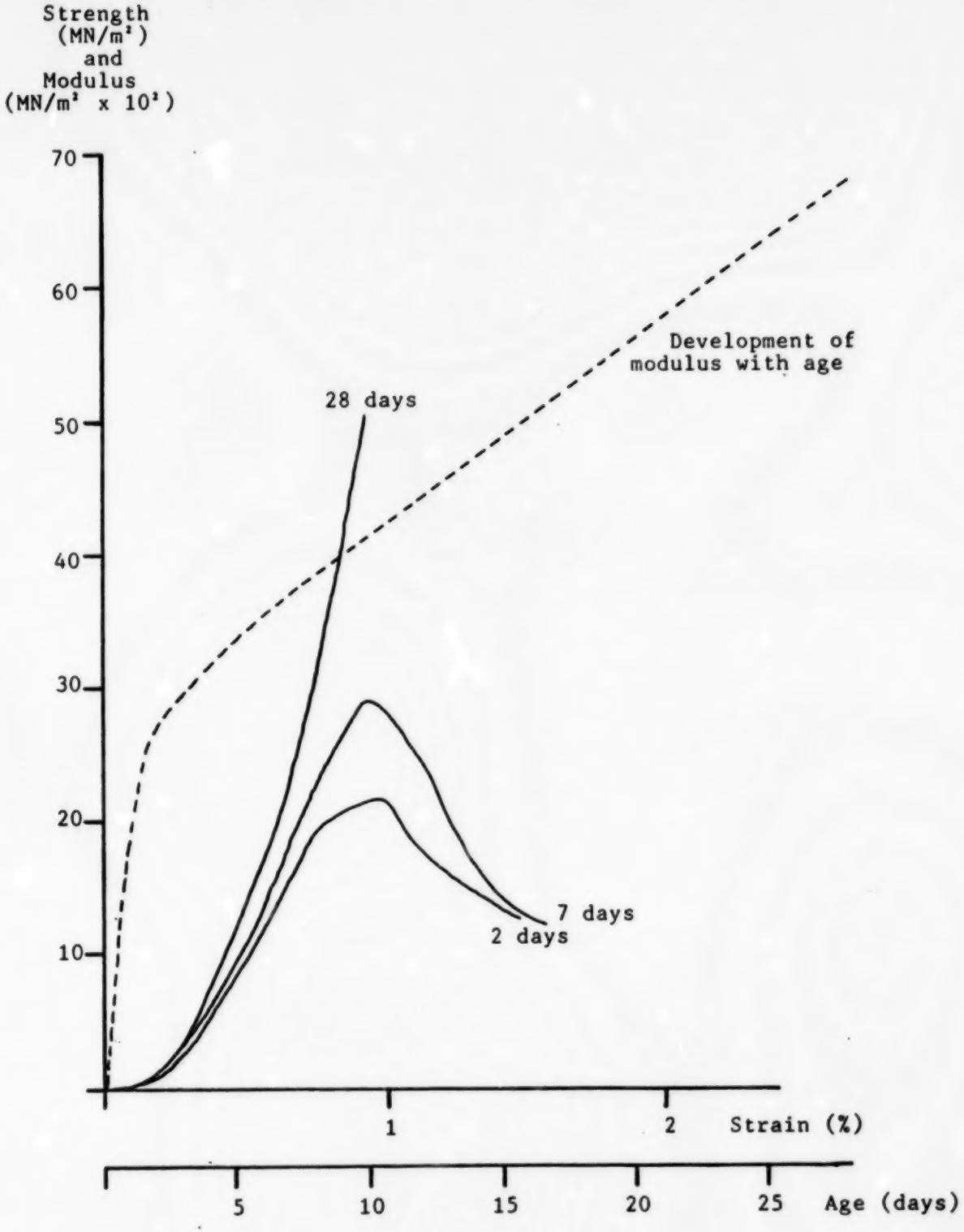


FIGURE 5: STRESS/STRAIN CURVES AND MODULUS DEVELOPMENT WITH TIME FOR KNAUF CUBE SAMPLES.

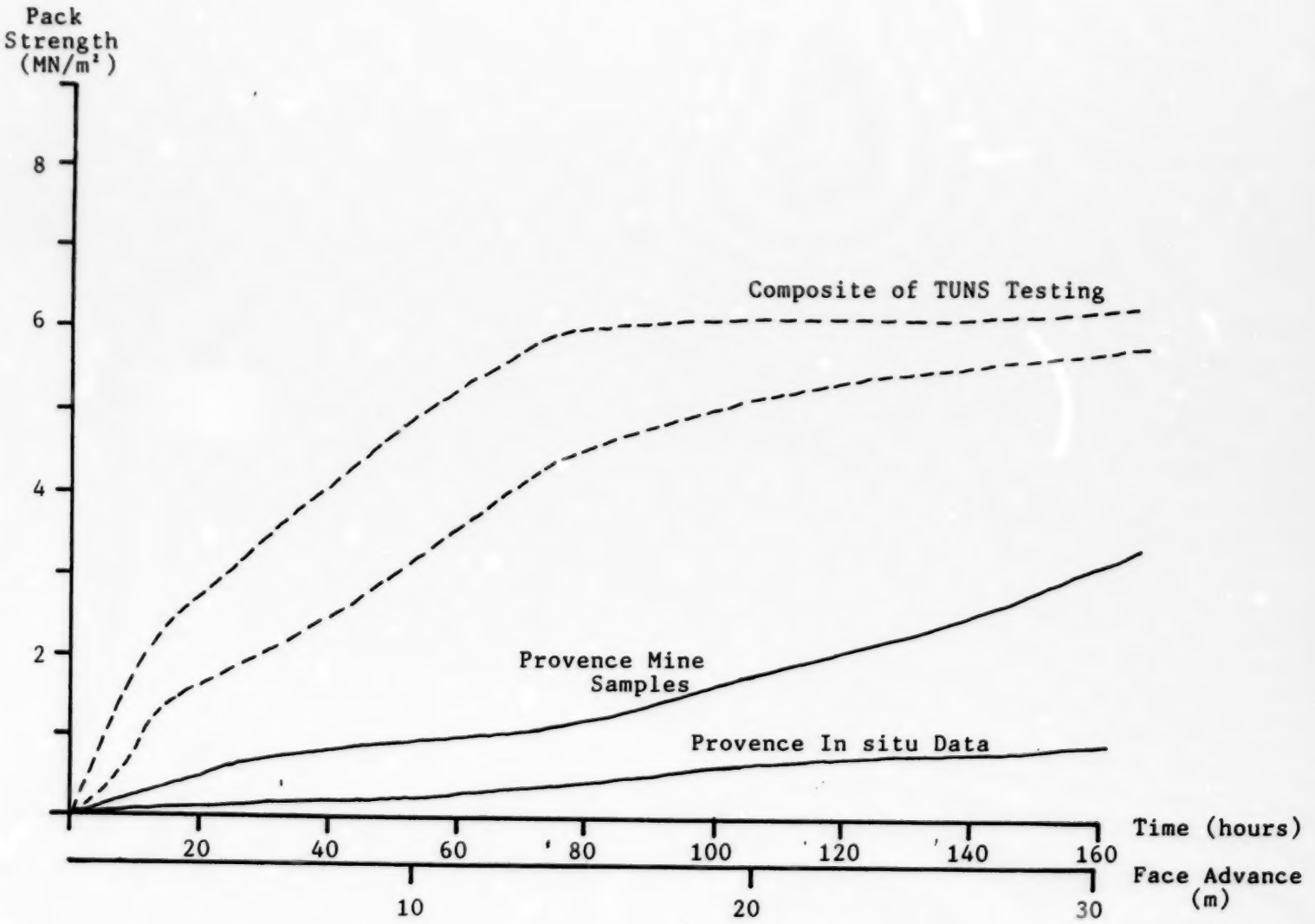


FIGURE 6: COMPOSITE STRENGTH DEVELOPMENT CURVES

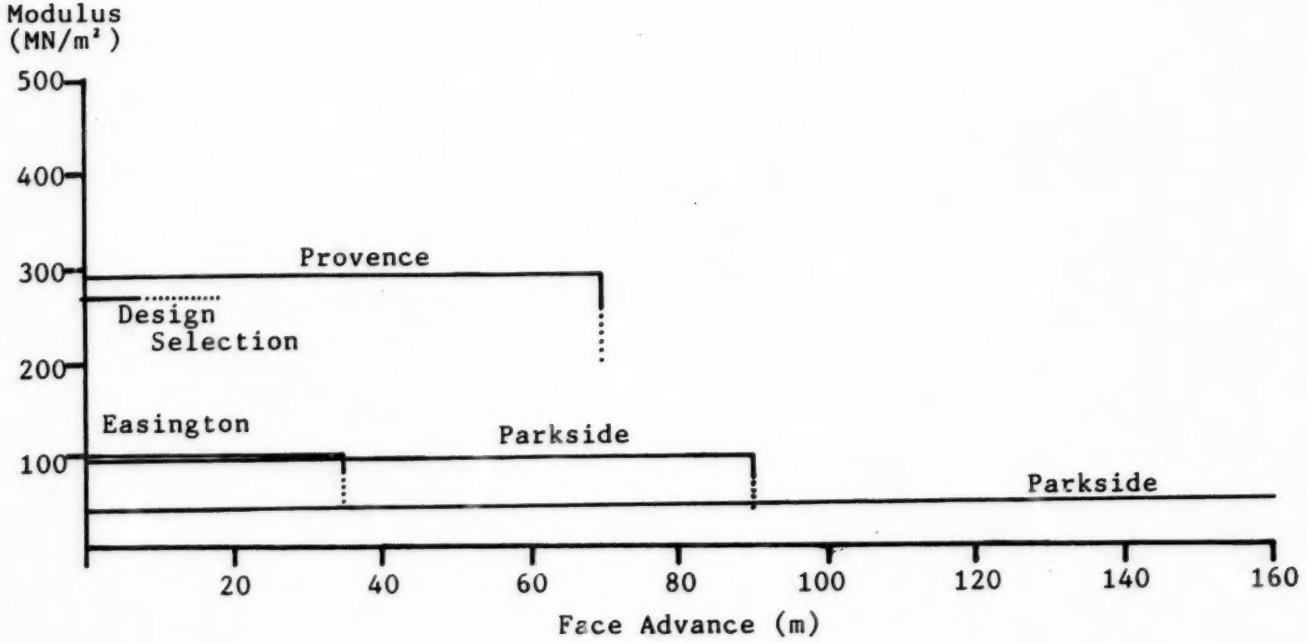


FIGURE 7: COMPOSITE MODULUS CURVES

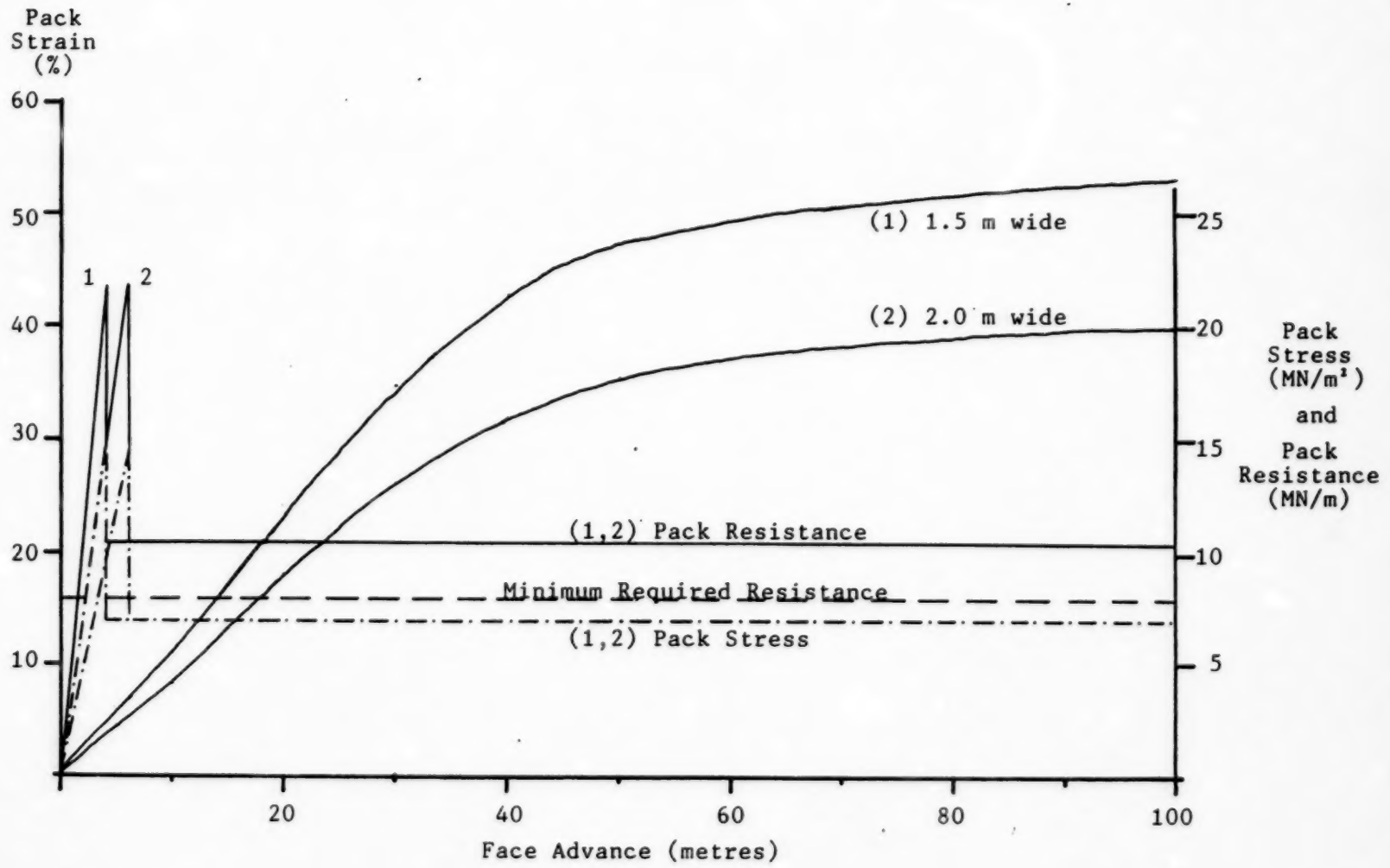


FIGURE 8: DEVELOPMENT OF PACK STRAIN, STRESS AND RESISTANCE